PHILOSOPHICAL

TRANSACTIONS

OF THE

ROYAL SOCIETY

OF

LONDON.

FRANKLIN INSTITUTE LIBRARY

FOR THE YEAR MDCCCLVIII.

VOL. 148.

LONDON:

PRINTED BY TAYLOR AND FRANCIS, RED LION COURT, FLEET STREET.

MDCCCLIX.

ADVERTISEMENT.

THE Committee appointed by the *Royal Society* to direct the publication of the *Philosophical Transactions*, take this opportunity to acquaint the Public, that it fully appears, as well from the Council-books and Journals of the Society, as from repeated declarations which have been made in several former *Transactions*, that the printing of them was always, from time to time, the single act of the respective Secretaries till the Forty-seventh Volume; the Society, as a Body, never interesting themselves any further in their publication, than by occasionally recommending the revival of them to some of their Secretaries, when, from the particular circumstances of their affairs, the *Transactions* had happened for any length of time to be intermitted. And this seems principally to have been done with a view to satisfy the Public, that their usual meetings were then continued, for the improvement of knowledge, and benefit of mankind, the great ends of their first institution by the Royal Charters, and which they have ever since steadily pursued.

But the Society being of late years greatly enlarged, and their communications more numerous, it was thought advisable that a Committee of their members should be appointed, to reconsider the papers read before them, and select out of them such as they should judge most proper for publication in the future *Transactions*; which was accordingly done upon the 26th of March 1752. And the grounds of their choice are, and will continue to be, the importance and singularity of the subjects, or the advantageous manner of treating them; without pretending to answer for the certainty of the facts, or propriety of the reasonings, contained in the several papers so published, which must still rest on the credit or judgement of their respective authors.

It is likewise necessary on this occasion to remark, that it is an established rule of the Society, to which they will always adhere, never to give their opinion, as a Body, upon any subject, either of Nature or Art, that comes before them. And therefore the

27733

thanks, which are frequently proposed from the Chair, to be given to the authors of such papers as are read at their accustomed meetings, or to the persons through whose hands they received them, are to be considered in no other light than as a matter of civility, in return for the respect shown to the Society by those communications. The like also is to be said with regard to the several projects, inventions, and curiosities of various kinds, which are often exhibited to the Society; the authors whereof, or those who exhibit them, frequently take the liberty to report and even to certify in the public newspapers, that they have met with the highest applause and approbation. And therefore it is hoped that no regard will hereafter be paid to such reports and public notices; which in some instances have been too lightly credited, to the dishonour of the Society.

The Meteorological Journal hitherto kept by the Assistant Secretary at the Apartments of the Royal Society, by order of the President and Council, and published in the Philosophical Transactions, has been discontinued. The Government, on the recommendation of the President and Council, has established at the Royal Observatory at Greenwich, under the superintendence of the Astronomer Royal, a Magnetical and Meteorological Observatory, where observations are made on an extended scale, which are regularly published. These, which correspond with the grand scheme of observations now carrying out in different parts of the globe, supersede the necessity of a continuance of the observations made at the Apartments of the Royal Society, which could not be rendered so perfect as was desirable, on account of the imperfections of the locality and the multiplied duties of the observer.

CONTENTS

OF VOL. 148.

I. THE BAKERIAN LECTURE.—*On the Stratifications and Dark Band in Electrical Discharges as observed in Torricellian Vacua. By* JOHN P. GASSIOT, *V.P.R.S.* page 1

II. *A Memoir on the Theory of Matrices. By* ARTHUR CAYLEY, *Esq., F.R.S.* . . 17

III. *A Memoir on the Automorphic Linear Transformation of a Bipartite Quadric Function. By* ARTHUR CAYLEY, *Esq., F.R.S.* 39

IV. *Supplementary Researches on the Partition of Numbers. By* ARTHUR CAYLEY, *Esq., F.R.S.* 47

V. *An Account of some recent Researches near Cairo, undertaken with the view of throwing light upon the Geological History of the Alluvial Land of Egypt.—Instituted by* LEONARD HORNER, *Esq., Vice-President of the Royal Society, Fellow of the Royal Society of Edinburgh, and Vice-President of the Geological Society.* 53

VI. *Researches on the Structure and Homology of the Reproductive Organs of the Annelids. By* THOMAS WILLIAMS, *M.D., F.R.S., Physician to the Swansea Infirmary. Communicated by* THOMAS BELL, *Esq., F.R.S., President of the Linnean Society, &c.* 93

VII. *On the Partitions of the* R-*Pyramid, being the first class of* R-*gonous* X-*edra. By the Rev.* THOMAS P. KIRKMAN, *M.A., F.R.S., Rector of Croft with Southworth* 145

VIII. *On the Isolation of the Radical, Mercuric Methyl. By* GEORGE BOWDLER BUCKTON, *Esq., F.R.S.* 163

IX. *Description of the Skull and Teeth of the* Placodus laticeps, OWEN, *with indications of other new Species of* Placodus, *and evidence of the Saurian Nature of that Genus. By Professor* OWEN, *V.P.R.S., Superintendent of the Natural History Departments in the British Museum* 169

X. *On the Properties of Electro-deposited Antimony. By* G. GORE, *Esq. Communicated by Dr.* TYNDALL, *F.R.S.* 185

XI. *On the Constitution of the Essential Oil of Rue. By* C. GREVILLE WILLIAMS, *Lecturer on Chemistry in the Normal College, Swansea* 199

XII. *On the Action of Ammonia on Glyoxal. By Dr.* H. DEBUS. *Communicated by Professor* TYNDALL, *F.R.S.* . . . . . page 205

XIII. *On some Physical Properties of Ice. By* JOHN TYNDALL, *F.R.S., Professor of Natural Philosophy in the Royal Institution of Great Britain* 211

XIV. *Researches on the Intimate Structure of the Brain, Human and Comparative.*—First Series. *On the Structure of the* Medulla oblongata. *By* J. LOCKHART CLARKE, *Esq., F.R.S.* 231

XV. *On the* MEGATHERIUM (Megatherium Americanum, CUVIER *and* BLUMENBACH).—Part IV. *Bones of the Anterior Extremities. By Professor* OWEN, *V.P.R.S., Superintendent of the Natural History Departments in the British Museum.* 261

XVI. *On the Anatomy and Physiology of the Spongiadæ. By* J. S. BOWERBANK, *LL.D., F.R.S., F.L.S. &c.* 279

XVII. *On the Physical Structure of the Old Red Sandstone of the County of Waterford, considered with relation to Cleavage, Joint Surfaces, and Faults. By the Rev.* SAMUEL HAUGHTON, *M.A., F.G.S., Fellow of Trinity College, and Professor of Geology in the University of Dublin. Communicated by Professor* TYNDALL, *F.R.S.* 333

XVIII. *On the Relative Power of Metals and Alloys to conduct Heat.*—Part I. *By* F. CRACE CALVERT, *Esq., F.C.S., Corr. Mem. Roy. Acad. Turin, Société de Pharmacie, Paris, &c.; and* RICHARD JOHNSON, *Esq., F.C.S. &c. Communicated by Professor* STOKES, *Sec. R.S.* 349

XIX. *On the Thermo-electric Series. By* AUGUSTUS MATTHIESSEN, *Ph.D. Communicated by* CHARLES WHEATSTONE, *Esq., F.R.S.* 369

XX. *On the Electric Conducting Power of the Metals. By* AUGUSTUS MATTHIESSEN, *Ph.D. Communicated by* CHARLES WHEATSTONE, *Esq., F.R.S.* 383

XXI. *On the Resistance of Tubes to collapse. By* WILLIAM FAIRBAIRN, *Esq., C.E., F.R.S. &c.* 389

XXII. *A Fourth Memoir upon Quantics. By* ARTHUR CAYLEY, *Esq., F.R.S.* . . . 415

XXIII. *A Fifth Memoir upon Quantics. By* ARTHUR CAYLEY, *Esq., F.R.S.* . . . 429

XXIV. *On the Tangential of a Cubic. By* ARTHUR CAYLEY, *Esq., F.R.S.* 461

XXV. *Astronomical Experiment on the Peak of Teneriffe, carried out under the sanction of the Lords Commissioners of the Admiralty. By Professor* C. PIAZZI SMYTH. *Communicated by* G. B. AIRY, *Esq., Astronomer Royal* 465

XXVI. *On Curves of the Third Order. By the Rev.* GEORGE SALMON, *Trinity College, Dublin. Communicated by* ARTHUR CAYLEY, *Esq., F.R.S.* 535

XXVII. *On the Magnetic Induction of Crystals. By Professor* JULIUS PLÜCKER, *of Bonn, F.M.R.S., H.M.R.I.* . . . . . page 543

XXVIII. *On the Development of Decapod Crustacea. By* C. SPENCE BATE, *F.L.S. &c. Communicated by Sir* W. SNOW HARRIS, *F.R.S.* 589

XXIX. *An Inquiry regarding the parts of the Nervous System which regulate the contractions of the Arteries. By* JOSEPH LISTER, *Esq., F.R.C.S. Eng. and Edin., Assistant Surgeon to the Royal Infirmary, Edinburgh. Communicated by Dr.* SHARPEY, *Sec. R.S.* 607

XXX. *On the Cutaneous Pigmentary System of the Frog. By* JOSEPH LISTER, *Esq., F.R.C.S. Eng. and Edin., Assistant Surgeon to the Royal Infirmary, Edinburgh. Communicated by Dr.* SHARPEY, *Sec. R.S.* 627

XXXI. *On the Early Stages of Inflammation. By* JOSEPH LISTER, *Esq., F.R.C.S. Eng. and Edin., Assistant Surgeon to the Royal Infirmary, Edinburgh. Communicated by Dr.* SHARPEY, *Sec. R.S.* 645

XXXII. *On the Structure of Lavas which have consolidated on steep slopes; with Remarks on the Mode of Origin of Mount Etna, and on the Theory of "Craters of Elevation." By Sir* CHARLES LYELL, *F.R.S., D.C.L.* 703

XXXIII. *Note on Archdeacon* PRATT'S *Paper "On the Effect of Local Attraction in the English Arc." By Captain* A. R. CLARKE, *R.E. Communicated by Lieut.-Colonel* JAMES, *R.E.* 787

XXXIV. *On the Organization of the Brachiopoda. By* ALBANY HANCOCK, *Esq. Communicated by* T. H. HUXLEY, *Esq., F.R.S.* 791

XXXV. *On* CHONDROSTEUS, *an Extinct Genus of the Sturionidæ, found in the Lias Formation at Lyme Regis. By Sir* PHILIP DE MALPAS GREY EGERTON, *Bart., M.P., F.R.S., F.G.S. &c.* 871

XXXVI. *On the Influence of Temperature on the Refraction of Light. By the Rev.* T. P. DALE, *M.A., F.R.A.S., and Dr.* J. H. GLADSTONE, *F.R.S.* 887

XXXVII. *On the Structure and Functions of the Hairs of the Crustacea. By* CAMPBELL DE MORGAN, *Surgeon to the Middlesex Hospital. Communicated by* GEORGE BUSK, *Esq.* 895

Index 905

APPENDIX.

Presents . . . . . [1]

LIST OF ILLUSTRATIONS.

Plate I.—Mr. Gassiot on the Stratifications and Dark Band in Electrical Discharges as observed in Torricellian Vacua.

Plates II. III. IV. V.—Mr. Horner on the Alluvial Land of Egypt.

Plates VI. VII. VIII.—Dr. T. Williams's Researches on the Structure and Homology of the Reproductive Organs of the Annelids.

Plates IX. X. XI.—Professor Owen on the Skull and Teeth of the *Placodus laticeps*.

Plates XII. XIII. XIV. XV. XVI. XVII.—Mr. J. Lockhart Clarke on the Intimate Structure of the Brain, Human and Comparative.

Plates XVIII. XIX. XX. XXI. XXII.—Professor Owen on the Megatherium.

Plates XXIII. XXIV. XXV. XXVI.—Dr. J. S. Bowerbank on the Anatomy and Physiology of the Spongiadæ.

Plate XXVII.—Mr. Crace Calvert and Mr. R. Johnson on the Relative Power of Metals and Alloys to conduct Heat.

Plates XXVIII. XXIX.—Mr. Fairbairn on the Resistance of Tubes to collapse.

Plates XXX. XXXI. XXXII. XXXIII. XXXIV. XXXV. XXXVI. XXXVII. XXXVIII. XXXIX.—The Admiralty Astronomical Experiment on the Peak of Teneriffe.

Plates XL. XLI. XLII. XLIII. XLIV. XLV. XLVI.—Mr. C. Spence Bate on the Development of Decapod Crustacea.

Plates XLVII. XLVIII.—Mr. J. Lister on the Cutaneous Pigmentary System of the Frog.

Plates XLIX. L. LI.—Sir Charles Lyell on the Structure of Lavas which have consolidated on steep slopes.

Plates LII. LIII. LIV. LV. LVI. LVII. LVIII. LIX. LX. LXI. LXII. LXIII. LXIV. LXV. LXVI.—Mr. Hancock on the Organization of the Brachiopoda.

Plates LXVII. LXVIII. LXIX. LXX.—Sir P. G. Egerton on Chondrosteus, an Extinct Genus of the Sturionidæ.

Plate LXXI.—Mr. C. De Morgan on the Structure and Functions of the Hairs of the Crustacea.

Adjudication of the Medals of the Royal Society for the year 1858 by the President and Council.

The Copley Medal to Sir Charles Lyell, for his various Researches and Writings by which he has contributed to the advance of Geology.

A Royal Medal to Mr. Albany Hancock, for his various Researches on the Anatomy of the Mollusca.

A Royal Medal to Mr. William Lassell, for his various Astronomical Discoveries and Researches.

The Rumford Medal to M. Jules Jamin, for his various Experimental Researches on Light.

The Bakerian Lecture was delivered by J. P. Gassiot, Esq., F.R.S., and entitled "On the Stratifications and Dark Band in Electrical Discharges as observed in Torricellian Vacua."

The Croonian Lecture was delivered by T. H. Huxley, Esq., F.R.S., and entitled "On the Theory of the Vertebrate Skull."

A List of Public Institutions and Individuals, entitled to receive a copy of the Philosophical Transactions of each year, on making application for the same directly or through their respective agents, within five years of the date of publication.

Observatories.

Armagh.
Cape of Good Hope.
Dublin.
Edinburgh.
Greenwich.
Kew.
Liverpool.
Madras.
Oxford (Radcliffe).

Institutions.

Barbadoes.....Library and Museum.
Calcutta.....Asiatic Society.
Geological Museum.
Cambridge.....Philosophical Society.
Dublin.....Royal Dublin Society.
Royal Irish Academy.
Edinburgh.....Royal Society.
London.....Admiralty Library.
Chemical Society.
Entomological Society.
Geological Society.
Geological Survey of Great Britain.
Horticultural Society.
Institute of British Architects.
Institution of Civil Engineers.
Linnean Society.
London Institution.
Medical and Chirurgical Society.
Queen's Library.
Royal Asiatic Society.
Royal Astronomical Society.
Royal College of Physicians.
Royal Geographical Society.
Royal Institution of Great Britain.
Royal Society of Literature.
Society of Antiquaries.
Society of Arts.
The Treasury Library.
United Service Museum.
Zoological Society.
Malta.....Public Library.
Manchester.....Literary and Philosophical Society.
Oxford.....Ashmolean Society.
Radcliffe Library.
Swansea.....Royal Institution.
Sydney.....University Library.
Woolwich.....Royal Artillery Library.

Belgium.

Brussels.....Royal Academy of Sciences.

Denmark.

Altona.....Royal Observatory.
Copenhagen.....Royal Society of Sciences.

France.

Paris.....Academy of Sciences.
Dépôt de la Marine.
Ecole des Mines.
Entomological Society.
Geographical Society.
Geological Society.
Jardin des Plantes.
Toulouse.....Academy of Sciences.

Germany.

Berlin.....Royal Academy of Sciences.
Society of Experimental Philosophy.
Bonn.....Cæsarean Acad. of Naturalists.
Frankfort.....Natural History Society.
Giessen.....University.
Göttingen.....University.
Hamburg.....Naturwissenschaftlicher-Verein.
Leipzig.....Royal Saxon Society of Sciences.
Mannheim.....Observatory.
Munich.....Royal Academy of Sciences.
Vienna.....Imperial Academy of Sciences.
Würzburg.....Physico-Medical Society.

Hungary.

Pesth.....Hungarian Academy of Sciences.

Italy.

Milan.....Institute of Sciences, Letters and Arts.
Modena.....Italian Society of Sciences.
Naples.....Institute of Sciences.
Rome.....The Academy de' Nuovi Lincei.
The Collegio Romano.
Turin.....Royal Academy of Sciences.

Java.

Batavia.....Batavian Society of Sciences.

Netherlands.

Amsterdam.....Royal Institute.
Haarlem.....Dutch Society of Sciences.
Rotterdam.....Batavian Society of Experimental Philosophy.

Portugal.

Lisbon.....Royal Academy of Sciences.

Russia.

Moscow.....Imperial Society of Naturalists.
Pulkowa.....Observatory.
St. Petersburgh..Imperial Academy of Sciences.

Spain.

Cadiz.....Observatory.
Madrid.....Royal Academy of Sciences.

Sweden and Norway.

Drontheim.....Royal Society of Sciences.
Stockholm.....Royal Academy of Sciences.

Switzerland.

Bern.....Allg. Schweizerischen Gesellschaft.
Geneva.....Société de Phys. et d'Hist. Naturelle.

United States.

Albany.....New York State Library.
Boston.....American Academy of Sciences.
Cambridge.....Harvard University.
Philadelphia.....American Philosophical Society.
Washington.....Smithsonian Institution.
Observatory.

The *fifty* Foreign Members of the Royal Society.

A List of Public Institutions and Individuals, entitled to receive a copy of the Astronomical Observations (including Magnetism and Meteorology) made at the Royal Observatory at Greenwich, on making application for the same directly or through their respective agents, within two years of the date of publication.

Observatories.

Altona.
Armagh.
Berlin.
Breslau.
Brussels.
Cadiz.
Cambridge.
Cape of Good Hope.
Coïmbra.
Copenhagen.
Dorpat.
Dublin.
Edinburgh.
Helsingfors.
Königsberg.
Madras.
Mannheim.
Marseilles.
Milan.
Munich.
Oxford.
Palermo.
Paris.
Seeberg.
Trevandrum.
Tübingen.
Turin.
Vienna.
Wilna.

Institutions.

Aberdeen	University.
Berlin	Academy.
Bologna	Academy.
Boston	American Academy of Sciences.
Brunswick, U.S.	Bowdoin College.
Cambridge	Trinity College Library.
Cambridge, U.S.	Harvard University.
Dublin	University.
Edinburgh	University.
	Royal Society.
Glasgow	University.
Göttingen	University.
Leyden	University.
London	Board of Ordnance.
	Queen's Library.
	Royal Institution.
	Royal Society.
Oxford	Savilian Library.
Paris	Academy of Sciences.
	Board of Longitude.
	Dépôt de la Marine.
Pesth	Hungarian Academy.
Philadelphia	American Philosophical Society.
St. Andrews	University.
St. Petersburgh	Imperial Academy.
Stockholm	Royal Academy of Sciences.
Upsal	Royal Society.
Waterville (U.S.)	College.

Individuals.

Christie, S. H., Esq.	Twickenham.
Lubbock, Sir John William, Bart.	London.
Lowndes Professor of Astronomy	Cambridge.
Plumian Professor of Astronomy	
President of the Royal Society	London.
Ross, Rear-Admiral Sir J. C.	Aylesbury.
Smyth, Rear-Admiral W. H.	Aylesbury.
South, Sir James	Kensington.
The Earl of Rosse	Parsonstown.

A List of Observatories, Institutions and Individuals, entitled to receive a Copy of the Magnetical and Meteorological Observations made at the Royal Observatory, Greenwich.

Observatories.

Bombay	
Cairo	
Cambridge, United States	Prof. J. Lovering.
Christiania	C. Hansteen.
Gotha	
Heidelberg	M. Tiedemann.
Kew	J. Welsh.
Kremsmünster	P. A. Realhuber.
Leipsic	Professor Mobius.
Marburg	Professor Gerling.
Prague	K. Jelinek.
Stockholm	Professor H. Selander.
Toronto	Professor Kingston.
Upsal	Professor Svanberg.
Washington	Lt. Maury, U.S. Navy.

Institutions.

Bombay	Geographical Society.
Bonn	University.
Bowditch Library	United States.
Cambridge	Philosophical Society.
Cherkow	University.
Falmouth	Royal Cornwall Polytechnic Society.
London	House of Lords, Library.
	House of Commons, Library.
	King's College.
	Royal Society.
	University College, Library.
Oxford	Radcliffe Observatory.
Paris	Meteorological Society.
St. Bernard	Convent.
Washington	Smithsonian Institution.
Woolwich	Office of Mag. and Met. Publication.

Individuals.

Bache, Dr. A. D.	Washington.
Barlow, P. W., Esq.	Charlton.
Ballot, Dr. Buys	Utrecht.
Demidoff, Prince Anatole de	Florence.
Dove, Prof. H. W.	Berlin.
Erman, Dr. Adolph	Berlin.
Fox, R. W., Esq.	Falmouth.
Gilliss, Lt. J. M., U.S. Navy	Washington.
Harris, Sir W. Snow	Plymouth.
Howard, Luke, Esq.	Tottenham.
Humboldt, Baron von	Berlin.
Kaemtz, Prof. L. F.	Dorpat.
Kreil, Prof. K.	Vienna.
Kupffer, A. T.	St. Petersburgh.
(Twelve copies for distribution to the Russian Mag. and Met. Obs.)	
Lloyd, Rev. Dr.	Dublin.
Loomis, Professor	New York University.
Lovering, Professor	Cambridge, U.S.
Melvill, Sir J. C.	East India House.
Pegado, Dr.	Lisbon.
Phillips, John, Esq.	Oxford.
Quetelet, A.	Brussels.
Reid, Major-Gen. Sir W., R.E.	London.
Riddell, Lieut.-Colonel, R.A.	Woolwich.
Sabine, Major-General, R.A.	London.
Senftenberg, Baron von	Prague.
Vernon, G. V., Esq.	Manchester.
Wartmann, Professor Elie	Geneva.
Younghusband, Capt., R.A.	Woolwich.

PHILOSOPHICAL TRANSACTIONS.

I. The Bakerian Lecture.—*On the Stratifications and Dark Band in Electrical Discharges as observed in Torricellian Vacua.* By John P. Gassiot, *V.P.R.S.*

Received January 6,—Read March 4, 1858.

1. The striated condition of the electrical discharge *in vacuo* that takes place when the terminal wires of Ruhmkorff's inductive coil are inserted into a well-exhausted receiver, in which a small piece of phosphorus has been previously placed, was first announced by Mr. Grove in his communication to the Royal Society, 7th January, 1852; his paper is printed in the first part of the Transactions for that year, and was subsequently published in the Philosophical Magazine of December 1852, with a supplementary note dated 9th June, wherein Mr. Grove states "that he had found the transverse dark bands could be produced in other gases when much attenuated, probably in all, and that he thought the reason why they are more easily seen in phosphorus vapour is that all the oxygen having been consumed, a better vacuum is formed."

2. I had, at the time, the pleasure of witnessing many of these experiments, which are now so well known to electricians; shortly afterwards I examined the discharge in a Torricellian vacuum: my apparatus consisted of a glass cylinder 6 inches long, in which two platinum wires are hermetically sealed about 4 inches apart; the cylinder forms the upper portion of a barometer, the lower part being made of the usual sized tubing; the mercury, when at the height of 30 inches, reaches to within about 6 inches of the cylinder; the mercury was carefully boiled in the usual manner by M. Negretti, and the apparatus fixed in my laboratory, where it at present remains as originally placed.

3. When the discharge is made with a Ruhmkorff's coil, by connecting the above platinum wires with the terminals of that apparatus, the cylinder is brilliantly illuminated with a dense white phosphorescent light, filling the entire vacuum, the intensity of the light depending on the energy of the battery. The mercury sinks at each discharge, but not the slightest trace of any transverse bands can be detected.

4. The phenomenon of stratifications in the discharge *in vacuo* were subsequently observed in Paris by M. Ruhmkorff, who obtained the effect by using the vapour of alcohol; they were again noticed by Masson, Du Moncel, Quet, and other continental

electricians, who all describe the *intense white light without stratification* produced in the barometrical vacuum*.

5. The Rev. Dr. ROBINSON, who has made a series of beautiful experiments with the inductive coil†, says, "Nothing satisfactory has yet been ascertained as to the cause of the stratification of light. Mr. GROVE appears to think that it arises from some vibration in the metal of the contact breaker, which produces a fluctuation in the inducing current; he finds that it is not always visible in the light caused by a single discharge, and that it is influenced by the nature of the metals between which the interruption spark occurs." Dr. ROBINSON, in a previous communication to the Royal Irish Academy‡, considered that the fact of their being produced by a single discharge, shows that they do not depend on the discontinuity of the current; and in a note to his paper of December 1856, he adds, "as the rarefaction proceeds, the intensity of the spark at the contact breaker decreases, and also we should suppose the vibration there, yet the stratification becomes more decided; this seems against Mr. GROVE's hypothesis." When the discharge from the terminals of RUHMKORFF's coil is taken in the air or *in vacuo* from thin platinum wires, the negative terminal becomes heated, and if the discharges are continued it is fused; in the voltaic battery it is the positive terminal that is heated by the discharge. *In vacuo* Dr. ROBINSON describes "the negative terminal as wrapt in a coat of bright blue light, through which, by an optical delusion, the platinum *seems* red-hot." Under some conditions the intense blue round the negative wire will appear without the red (43.), in other conditions it will appear red as if intensely heated, and in other instances white.

6. In Mons. DU MONCEL's work on the Inductive Coil, the stratifications are figured as concave towards the positive end, the concavity *decreasing* as the bands extend towards the negative; at the centre they become straight, and then gradually concave towards the negative terminal *until* they arrive at the dark space which separates the bands from the negative discharge. Dr. ROBINSON, in the paper of January 1856, already alluded to, has given a drawing of the beautiful stratifications obtained by him in the vacuum of an air-pump prepared with great care over sulphuric acid (34.).

7. In Dr. ROBINSON's figure the bands are all concave towards the positive terminal, this being a globe, while the negative is a point. I can bear witness to the correctness of both representations; for although I have not had the pleasure of seeing Dr. ROBINSON's experiments, I have seen and obtained a somewhat similar figure to that which he has represented by using Mr. GROVE's method with phosphorus vapour, while in the vapour of naphtha I have on other occasions observed the discharge as figured by DU MONCEL; these different effects do not however in any way arise, as might be assumed, from the difference of vapour, but from other causes, which will be explained in this paper.

* In the Torricellian vacuum the inductive spark is white, filling the whole tube.—NOAD's 'Electricity,' 4th edition, p. 742.

† Proceedings of the Royal Irish Academy, 8th December, 1856.

‡ Proceedings of the Royal Irish Academy, January 14, 1856.

8. The conditions necessary to enable the experimentalist to produce the phenomena of the striæ or band discharge, have been stated by different authors to be as follows:—1st, that the vacuum in the receiver should be as perfect as can be obtained by the air-pump; 2nd, that care should be taken to absorb all trace of moisture; and lastly, that means should be used to introduce the vapour of naphtha or phosphorus, or other similar bodies.

9. The induction apparatus used in the following experiments was constructed for me by Mr. LADD; in form it is similar to that of M. RUHMKORFF; the primary coil consists of three layers of No. 12 copper wire, total length 50 yards; the secondary, about three miles of No. 35 covered with silk, each layer of the secondary coil being carefully insulated by folds of thin gutta percha; with four or five cells of the usual size nitric acid battery, this apparatus gives a discharge in air of 4½ inches; but my experiments, except when otherwise described, were made with only one cell, and generally without any condenser; this is separate from the apparatus, it consists of two sections, one of 50 and the other of 40 square feet of coated surface, which can be used either separately or connected.

10. While pursuing my experiments, it occurred to me that an apparatus similar in some respects to that used by DAVY, could without much difficulty be constructed, which would enable me not only to make experiments in a Torricellian vacuum, but also with great facility in any gas which does not act on mercury: Plate I. fig. 1 represents this apparatus. In the glass tube, two platinum wires, *a* and *b*, are carefully sealed about 6 inches apart; the tube is filled with pure mercury. A stopcock, fixed at C, can, by means of a flexible tube, be connected with an air-pump. When the air is extracted from the ball of the apparatus, the mercury sinks in the tube, and in this manner the Torricellian vacuum is formed, the mercury in the tube descending to "*d*."

11. In my first experiments the discharge did not exhibit the uniform white light of the Torricellian vacuum, but striæ in confused or irregular forms; and although there was not the slightest appearance of even a trace of air in the tube when first filled with mercury, a minute bubble constantly appeared after the discharge had been continued for three or four minutes, and the mercury was allowed to rise in the tube. On incautiously letting in the mercury after the lower wire had been heated by the negative discharge, the tube broke.

12. This experiment having convinced me that under some conditions the stratification could be produced in a Torricellian vacuum, I ordered other similar apparatus to be made, one of which I directed should not only be very carefully filled, but that the mercury should be boiled in the tube. The effect I obtained fully compensated me for the trouble I had taken. In this apparatus the discharge from the coil, when excited by a *single* cell of GROVE's battery, the upper wire being negative, consisted of eight or ten distinct stratifications, extending from the positive wire to the dark space, while the usual blue flame surrounding the intense red, which has the appearance of red heat, is visible on the negative wire. On reversing the direction of the primary current by the

commutator, the stratifications appear from the upper wire, while the lower, which is now negative, has the blue and red glow; but in this case there is a phosphorescent light from the surface of the mercury at *d* to the lower wire.

13. When the connexion with the battery is broken, the negative wire (if the discharge has been continuous for a *short* time) is found to be black, and the sides of the glass tube covered for a certain distance with minute greyish dust, which comes off as the mercury ascends in the tube; this is probably the condensed vapour of mercury, from the vicinity of the heated negative wire, as the mercury removes the particles as it ascends the tube, without leaving any trace on its surface.

14. In some experiments which I made as far back as October 1854, I noticed a deposit when the discharge was made from platinum wires sealed in a glass globe, exhausted by means of the air-pump. I showed the globe to Dr. FARADAY, who kindly tested and examined the deposit, and found it to be finely divided platinum in the metallic state. At the time I did not follow up the experiment; it now occurred to me to test this action in the apparatus, similar to fig. 1, Plate I. (of which I had several constructed): I made the discharge constantly in the same direction, the upper wire being negative; the result was that the upper portion of the tube, as far down as a line drawn even with the end of the wire, was covered with platinum in a minute state of division; when this deposit is examined by transmitted light it is translucent, presenting to the eye an extremely thin bluish-black film; but by reflected light, either on the outside or inside, it has the appearance of highly polished silver, reflecting the light as from the finest mirror*.

15. When the upper wire is negative and the lower positive, if the mercury in the globe is allowed slowly to ascend the tube the stratifications collapse, but the dark band between them and the negative glow remains; as the mercury rises, the stratification merges into a series of rings on the surface of the mercury, which, when the circuit of the primary is broken, is not found to be tarnished, but as bright as when the experiment commenced.

16. If the upper wire is positive and the lower negative, as soon as the mercury ascends above the negative wire, a beautiful lambent bluish white vapour appears to arise, while a deep red stratum becomes visible on the surface of the mercury; as the mercury ascends in the tube, the stratified discharge from the positive wire collapses, giving the appearance of a compressed spiral; on exhausting the globe the mercury descends in the tube and the stratification expands, as if the pressure on a spiral spring had been removed.

If, during the exhaustion, the descending mercury is permitted to remain stationary

* Since I wrote the above my attention has been drawn to Mr. GROVE's paper in the Philosophical Magazine, March 1853, of which the following is an abstract.

On the interior of the tube was a dark pulverulent deposit, far too minute in quantity for analysis, but which had evidently proceeded from the platinum; the only possible mode in which I can account for this experiment is, that this deposit consisted of an oxide or peroxide of platinum.

for a few seconds, the discharge being continued, the tube will (at each place where the mercury has rested) be found coated with minute particles of condensed mercurial vapour, which clear off when the mercury ascends.

17. I have stated (10.) that I had several of the apparatus (fig. 1) constructed, but in no two could I obtain precisely the same result: in some the stratification was more or less distinct, in others scarcely visible, but in all a residuum of air, more or less, could be detected when the mercury was allowed to ascend the tube; but it appeared surprising that there should be so marked a difference in the discharge when, as in some instances, so very minute a quantity of air (less than $\frac{1}{6000}$th of the contents of the tube) was present.

Mr. Casella, who had made all the glass apparatus already described (with the exception of the barometer), placed one of his most intelligent workmen at my disposal; this enabled me to proceed with my experiments, and I had five separate tubes prepared in the following manner:—three were of the same length and dimensions as the tube of the original apparatus, Plate I. fig. 1; two were made of the usual barometer tubing, the wires of the one *set* being 10 inches, and of the other 16 inches apart.

Each of these tubes was filled with pure mercury, carefully boiled; a tube about 34 inches in length being attached to each, also filled with mercury; the apparatus was inverted into a basin of mercury, thereby forming the usual barometrical vacuum, and the tubes were then sealed about 4 inches below the lower platinum wire.

18. Designating these tubes (Plate. I. fig. 2) as A, B, C, D and E, the stratification in A is nearly equal to what I obtain in my best mercurial apparatus (12.). In B the discharge is of conical form, and the stratification visible, but confused and indistinct. In C the discharge is in a wavy line, without any stratification. In D the discharge is clear, bright and white, but no appearance of stratification. In E the stratification is very distinct and well-defined.

19. On examining the apparatus B, a minute bubble of mercury can be perceived in the stem, and in C there is evidently moisture in the lower part, below the platinum wire. Taking advantage of this accident, I inserted the stem of C in a freezing mixture of pounded ice and muriatic acid. The change in the character of the discharge was very striking; instead of the straight luminous line, the discharge assumed the conical form, exhibiting the striæ in a very much more clear and distinct manner than in B, though not quite so good as in A.

20. I could not but feel assured that there must have been something wrong in the mode of obtaining vacua which exhibited such irregularity of action, and I determined on trying an experiment for which I had long since made preparation, viz. to examine whether any different effect would take place in a barometrical vacuum obtained by the non-boiling process first suggested by Mr. Welsh, and which he so successfully carried out in filling the large barometer of the Observatory at Kew; an apparatus so exhausted might also effectually test Mr. Welsh's process of filling a large barometer, the value of which those who are practically acquainted with the difficulty of boiling such

a mass of mercury as is contained in a tube of upwards of an inch internal diameter and 34 or 35 inches in length, can fully appreciate.

Mr. WELSH kindly superintended at Mr. CASELLA'S the filling of a tube on his principle (Plate I. fig. 3): the process used by this gentleman, which avoids all the difficulty of boiling, has been fully described in the Philosophical Transactions for 1856*. The only difference in the present instance is the previously inserting the platinum wires at *a* and *b*, the tubes being hermetically sealed at *d*, about 4 inches from the wire *b*.

The result realized to the fullest extent our expectations: in this tube the bands were clear, well-defined and distinct; and, provided care be taken in manipulating with the coil, so as always to send the discharge in the same direction, the platinum coating is deposited on the portion of the tube surrounding the negative wire, but none at or near the positive.

21. With this tube I obtained the stratification by the discharge of the electrical machine. This experiment was first made by me on the 28th of December last, in the Theatre of the London Institution, in the presence of Professor TYNDALL and Mr. MALONE, connexion being made from one platinum wire to the conductor of a 4-feet electrical machine, while the other wire was attached to the rubber. On turning the plate the discharge took place through the tube, filling it with the usual phosphorescent light, but exhibiting the striæ very distinctly.

22. The cause of the dissimilarity in the discharge of A, B and C, and of D and E, although respectively of similar dimensions, did not arise from any dissimilarity in the mode of obtaining the vacuum, but from the glass tubes not having been, previous to the insertion of the mercury, equally well cleaned or equally well deprived of moisture, a circumstance which Mr. WELSH has shown is indispensable in the construction of a good barometer, and this cleansing can only be obtained by mechanical means; in C the moisture is, as I have observed, perceptible, and in this the discharge is most imperfect.

With a tube prepared on Mr. WELSH'S principle, and a moderate-sized RUHMKORFF'S coil excited by a single cell of GROVE'S nitric acid battery, the phenomena of the stratified discharge can be seen and examined with ease, without the trouble and uncertain manipulation of the air-pump, or using phosphoric and other vapours.

23. My next experiments were made with apparatus the form and size of which were different to those I had already used, but which had been made previous to experimenting with the last-named tube, fig. 3. Fig. 4, Plate I., represents an apparatus with moderate-sized thermometer tubing, having wires, *a* and *b*, inserted as before, with stopcock C for exhausting by air-pump: in this apparatus the discharge is divided into alternate white and dark bands, having the appearance of ruled lines.

24. Fig. 5 represents a similar apparatus, but of a pear shape, 3 inches internal diameter; the wires are 5 inches apart from point to point. Although great care had been taken in boiling this large vessel of mercury, containing about 10 lbs. of the metal, the vacuum was not found to be perfect, and moreover the mercury remained deposited

* vol. cxlvi. p. 507.

in a film on some portions of the vessel when it was exhausted. In this condition of the apparatus the discharge was similar to what I had often obtained (with Mr. GROVE's experiment) in the vapour of phosphorus, the stratifications being very distinct near the upper or positive wire, and spreading towards the negative in a confused manner. If the mercury was permitted to rise above the negative wire, as in the former experiment (16.), the surface of the mercury would become covered with the bright red glow, surmounted by a thin film of white flame, the entire surface being thus covered until it had risen to within 4 inches of the positive wire: from this point, as the mercury rose, the diameter of the red spot gradually reduced in size, until the mercury was within ·1 or ·2 of an inch of the wire, when the glow contracted into a minute spot. In this manner the diameter of the base of the conical discharge could be measured, showing its increase in proportion to the length of the discharge when it is not compressed by a narrow tube.

25. Although great care had been taken in boiling the mercury in this apparatus, the results obtained were so unsatisfactory, in respect to the stratification, that I had the mercury withdrawn and the glass thoroughly cleaned: for this purpose it became necessary to remove the upper wire; this afforded me an opportunity of examining it. This wire had been generally used as the negative terminal; it was black and rough, as if much corroded, evidently from the abstraction of the minute particles deposited on the surface of the glass tube (14.); the wire being resealed in the tube, which was subsequently filled with entirely new mercury, a minute bubble of air remained, but the result obtained was so satisfactory, that I have not attempted to remove it. In Plate I. fig. 5, I have endeavoured to give a faint representation of the beautiful appearance of the stratification, as exhibited when the upper wire is positive and the lower negative. If the mercury is permitted to ascend, immediately it covers the negative wire the stratifications disappear, and the interior of the globe is filled with bluish light; a bright spot of light is visible on the end of the positive wire, but the negative mercury no longer exhibits the red glow of the former experiment, its entire surface, until it ascends to within an inch of the positive wire, being covered with a brilliant white phosphorescent film about $\frac{1}{8}$th of an inch in thickness.

26. Fig. 6 represents an apparatus having for terminals platinum balls $\frac{1}{8}$th of an inch in diameter instead of the wires, the distance between each being about 5 inches; with this apparatus the stratifications *at first* were nearly the same as in the previous experiment with points (12.); but when the mercury had been permitted to rise and fall in the tube several times, a very marked difference in the character of the stratification was observed; instead of exhibiting eight or ten divisions, they were reduced to two or three, of the shape as in fig. 6.

These stratifications did not take place directly from the end of the positive ball, but from that portion of the wire that was immediately in connexion with the glass; by carefully manipulating with the contact breaker, the discharge could be observed to travel down the wire, overlap the ball and descend into the tube, followed by another,

and sometimes a third and fourth, each separated by the dark striæ; they were beautifully drawn out by approaching to them a magnet.

27. When the upper ball is positive and the mercury is permitted to rise so as to cover the lower or negative ball, the stratifications instantly disappear, as in the previous experiment (26.); the tube is then filled with beautiful phosphorescent light.

The difference in the stratification from wires and balls in this experiment probably arose from the latter having received a coating of liquid mercury, and the greater mobility of that metal which thus formed the terminals. In this apparatus there was not any fixed deposit on the glass; near the negative ball, during the discharge, mercurial vapour condensed on the tube in a considerable quantity, but this came off when the mercury ascended the tube and came into contact with it; there was not any sign of deposit near the positive ball, or on any other portion of the tube.

28. Plate I. fig. 7 represents a tube 28 inches long and of about $\frac{3}{8}$ths of an inch internal diameter; it is cemented into a brass plate, *a*, and when carefully filled with mercury, was placed on the open mouth of a receiver on the air-pump, the lower part of the tube being at the same time immersed into a tumbler of mercury; platinum wires were sealed in as before, only in this instance they were 18 inches apart; by this arrangement I could with facility regulate the length of the discharge from the $\frac{1}{16}$th of an inch to 18 inches, either suddenly or very gradually, by allowing the air to enter into the receiver, or by exhausting it with the pump; the vacuum was not so good as I could have desired, *a very minute* bubble of air always remaining; but the stratifications were very distinct when the discharge traversed the full length of 18 inches.

If the mercury is permitted to ascend the tube, immediately it covers the lower wire, the upper being positive, a dark discharge, 3 inches in length, appears; immediately contiguous to this dark discharge there are about four stratifications to the inch; towards the upper part of the tube they appear as compressed; about 9 inches from the positive terminal they are six or seven to the inch, but above this they are very close; when the mercury ascends to within from 7 to 5 inches of the positive terminal, all appearance of stratifications ceases, and in lieu thereof we have the white phosphorescent light of the barometrical discharge (4.). If, instead of one or two cells, the coil is excited by four or five, and care is taken to manipulate with the contact breaker so as to give sudden discharges, the lower portions of the striæ assume a form as Plate I. fig. 8, which represents the diameter of the tube and the striæ as they appear in the apparatus.

29. If the hammer of RUHMKORFF's contact breaker is removed, or the contact breaker of BENTLEY's or of HEARDER's is separated, the primary circuit can be completed by wires attached to the screws usually used for the condenser, which in the following experiments is used.

Having fixed two flexible wires (those I use are made of wire-rope covered with the India-rubber tubing) in the screws as above, turn the commutator so as to allow the current to pass through it: the primary circuit can now be completed and the secondary charged, by means of the flexible wires attached to the screws.

30. Let the terminal of one wire be firmly fixed to a bright copper plate, $\frac{1}{8}$th of an inch thick, having a sharp edge in order to ensure a sudden disruption of the primary current; complete the circuit by steadily pressing the end of the other wire on the plate, using one or two of GROVE's cells to excite the primary: no trace of any discharge will be perceived in the tube.

Pressing the wire on the plate so as to ensure perfect continuity, bring it across the sharp edge of the copper plate, and a quick, sudden break of the battery circuit can be effected; the stratifications will appear in the tube in a very distinct and beautiful manner; in a discharge of 18 inches the entire tube is filled with them to the extent of the dark band (36.); the more sudden the break, the more distinct will be the effects.

If the experiment is repeated by making contact with the wires without the plate, or by dipping them in the mercury, the same results are obtained. I have made the experiment of a single disruption of the primary circuit under every variety of form, and in no instance did it fail, although unless care is taken, it might be fairly doubted whether the discharge was single or continuous.

31. When the intensity of the primary circuit is increased by using eight or ten of GROVE's battery, the stratification is plainly visible and *on making contact*, but in an opposite direction and very inferior in intensity or brilliancy to the discharge on breaking; the effects are much heightened by the condenser.

32. Although no signs of any discharge can be observed in the *vacuum* on making contact when the primary current is excited by a single cell, still evidence of action in the secondary coil can be detected by the galvanometer, as also in the following manner:—let the ends of two platinum wires attached to the terminals of the secondary coil rest on a piece of bibulous paper, moistened with a solution of iodide of potassium; complete the circuit of the commutator, and then remove the paper: iodine will be evolved from one terminal:—make contact with the moistened paper, keeping the primary circuit complete; remove the paper; no trace of iodine is perceivable, proving that in this state there is no evidence of a current in the secondary wire: again make contact with the moistened paper and the platinum wire, break the circuit with the commutator, and iodine is immediately evolved at the opposite terminal in a much larger quantity than the former.

33. In the phenomena of the induction spark, time appears to be an important element, at least it is so in the secondary coil as at present constructed; experiment teaches us that the effect from breaking is far more powerful than that from making contact. In RUHMKORFF's coils we have, however, not only the induced effect from the primary current, but we have the induced effect from the powerful electro-magnet; to attain the maximum effect of the latter time is essential*, *particularly* if the primary coil is formed of several convolutions of the wire ("three convolutions are used by RUHMKORFF").

* Time, as is well known, is necessary for the development of electro-magnetism, and M. MATTEUCCI, in his recent valuable book on induced electricity, has shown some remarkable results flowing from this fact. —GROVE, Philosophical Magazine, January 1855, p. 2.

If the wires or iron core are made of well-softened iron, although they require some time to obtain their maximum power, they lose it instantly; consequently the more sudden the contact is broken, the clearer and more intense will the discharge appear *in vacuo*.

34. I have already alluded to the form of the stratifications as figured in M. DU MONCEL'S pamphlet and other papers, as also to that of Dr. ROBINSON (4.); in the former they are concave towards the positive terminal, gradually becoming parallel towards the centre and then concave to the negative; in Dr. ROBINSON'S drawing they are all concave towards the positive; the former is the appearance the stratifications exhibit when eight or ten or more cells are used to excite the primary, and when by the rapidity of the action of contact breaker the discharges alternate from each wire and intermingle with each other; Dr. ROBINSON states he used three and subsequently only one of GROVE'S; hence the difference in the representations.

35. While experimenting with a battery of thirty or forty cells, I observed that the positive terminal, when the discharge was taken in air, became heated as soon as the negative; the cause of this, as well as the difference in the stratifications, as figured by M. DU MONCEL and Dr. ROBINSON, is explained by the preceding experiments: in Dr. ROBINSON'S experiments the primary current was excited by only three cells of GROVE'S battery, which will not produce any sign of a luminous discharge *in vacuo* on *making* contact; the figure as depicted by that gentleman is the discharge on breaking contact; and when the vacuum was improved by allowing it to remain for several days, exhausting the receiver four times, each time filling it with dry hydrogen, the same figure was produced by a single cell of GROVE'S battery. The discharge, as figured in M. DU MONCEL'S work, has precisely the appearance which is produced when a sufficient series of GROVE'S batteries is used, which will produce a luminous discharge on making as well as breaking contact.

36. Whether the discharge is taken in a tube of 5 inches or one of 18 inches, or even of 5 feet 3 inches (41.) in length, the full intensity of the discharge is visible at a single contact, exhibiting from 80 to 100 stratifications, their separation from each other evidently depending on the density of medium through which the discharge takes place, or the increased energy of the primary current.

The luminous arc of the voltaic battery carries with it minute particles from the terminals, and experiment has shown that an emanation of particles takes place from both wires, although more powerfully from the positive to the negative*; with the inductive coil the emanation of particles only proceeds from the negative, not in a direct line to the positive, but laterally; if the *negative* wire is inserted from the top of the tube, these emanations are deposited on the sides of the glass, more dense at the part nearest the wire, but not below the level of the extreme end of the negative wire; at the positive there is not any sign of deposit, and the wire remains bright and clear.

37. If care is taken so as to make the discharge in one direction, the negative wire

* DE LA RIVE'S 'Electricity,' vol. ii. p. 288.

will be found to have become black and rough (25.), so as to have the appearance of being corroded; the glass tube to a line with the end of the wire will be covered with a deposit of platinum, which reflects light either from the inside or outside, but when examined by transmitted light will be found (unless the action has been continued for a considerable time) to be translucent, presenting a layer of a bluish-black colour.

38. Under certain conditions, when the discharge is heightened by increasing the intensity of the battery to the maximum, but short of the double discharge, in order to prevent the confusion arising therefrom, the effect on the stratifications is much altered, as in fig. 8, Plate I.: this experiment, which requires a little care in the manipulation of the contact breaker, exhibits a direction of force from the positive to the negative, and in no way connected with the passage of particles from pole to pole, as in the voltaic discharge.

39. The spheroidal form of the voltaic arc has been assumed to arise from the mutual repulsion of the parts detached from each polar extremity*: De la Rive has shown that the same effects are produced by frictional electricity; the distribution of currents in the liquid electrolyte is also of this character, as are the forces of the north and south poles of two magnets when placed in a line with each other. In a moderately good vacuum the discharge from the secondary coil is in the form of a cone, having its apex at the positive and its base towards the negative, Plate I. fig. 2 B; and in this medium it is immaterial whether this positive discharge is taken from a point or a base: the discharge in such a medium is always in this form.

FRANK INSTITUTE LIBRARY

40. That the glow discharge from the secondary coil is not due to the particles emanating from the negative wire is probable, from such particles being always deposited in a lateral direction from the wire, and not beyond the line on the glass tube even with the end of the negative wire, from whence, to the top of the tube, the platinum is copiously deposited; and although the discharge would seem to show by its form that its direction is from the positive terminal, and that whatever may be the separation between the positive and the negative terminal, the positive discharge or stratifications generally proceed to within a short distance of the negative, still the negative plays an important part in this form of the electrical discharge,—witness the brilliant luminosity by which it is surrounded, and the remarkable heating of the wire whether *in vacuo* or in air (5.); that there is also an apparent repelling force is shown by the stratifications receding as the mercury ascends, leaving, in some instances, 3 or 4 inches of the dark discharge, the stratifications gradually collapsing until in a long tube they disappear.

41. In order to test whether any signs of interference could be observed by making the discharges of two separate coils intermingle with each other, two instruments were constructed, Plate I. figs. 9 and 10, in each of which four platinum wires were carefully sealed: a reference to these figures will explain the manner in which the experiment was made; the terminals of one coil were attached to $a\,a'$, and of another to $b\,b'$; in

* De la Rive's 'Electricity,' vol. ii. p. 296.

fig. 9 the discharges were parallel to each other; in fig. 10 one discharge was made in the centre of the other.

Whether the discharges were made in the same direction or opposed to each other, there were not any signs of interference, the separate stratifications from the discharge of each coil remaining visible, although producing a degree of confusion from their interposition.

These two experiments will probably be considered strong evidence to show that the stratifications in the positive discharge do not arise from interference, but from a succession of impulses or pulsations from the force meeting a resisting medium. The positive division of the discharge is of a greater intensity, and consequently much greater length than the negative; indeed, as yet, we do not know the limit; I have obtained the stratifications in a tube of 5 feet 3 inches length, in which as in that of 18 inches they are beautifully shown.

42. The dark discharge between the positive and the negative I venture to assume arises from interference. When the discharge is taken, in the apparatus, Plate I. fig. 7, it is curious to observe the stratifications retreating from the negative as the mercury ascends the tube, or following them as they descend when the vessel is being exhausted, the dark line of discharge being compressed or expanded in proportion as the length of the stratifications is increased or decreased.

Mr. Grove, in his note to his paper, to which I have already referred, says, "having in my mind the analogy of interference, it seemed to me that this dark space might be due to the crossing of the lines of discharge from successive points of the needle, the knob, or plate from which the negative discharge issues*.

43. I made several experiments in order to ascertain the cause of the red strata on the negative mercury (12. 16. 23. 25.), which was evidently identical with the red glow of the platinum, described by Dr. Robinson (5.) as giving the wire, by an optical delusion, the appearance of being red-hot; in one of the apparatus (Plate I. fig. 1) the negative terminal, lower wire *b*, in a short time became, for about half its length inside the tube, coated with mercury, while the remaining half presented the corroded black appearance already referred to (25.); in this state, when the discharge was made, the red glow was very brilliant on the black portion of the wire; but the other, which was the furthest from the glass, was enveloped with white phosphorescence.

The pear-shaped apparatus (23.), Plate I. fig. 5, is filled with new mercury; in this there is now not any sign of red glow, while in the long tube (fig. 7) it is most brilliant, giving the lower portion of the negative discharge a beautiful rose-coloured tint, gradually shading off through pale blue into the dark space; the glow was also seen in apparatus, Plate I. fig. 1. I have not any note whether the mercury inserted in this apparatus was new, but that in the long tube (fig. 7) had been previously used and cleaned in the usual manner, first with dilute nitric acid, then with water, the mercury being subsequently dried. The red glow on the surface may be due to some impurity in the mercury; it is always

* Philosophical Magazine, December 1852, p. 514.

far more brilliant on platinum wire after the discharge has been made for a short time, probably from the incandescence of the minute points of the metal in the act of emanation as they are deposited on the glass; if a very thin platinum wire is used for the negative terminals, it will be fused. I have already mentioned, that in the ball apparatus (fig. 6) there was not any discharge or emanation of particles of mercury from the positive ball, but much from the negative, another evidence that the force from the positive is not accompanied by the transfer of particles of the metallic terminal.

Action of a Magnet on the Inductive Discharge.

44. The stratifications are very powerfully affected by a magnet. When the discharge is made from wire to wire, Plate I. figs. 1, 2, 3 or 7, if a horseshoe magnet is passed along the tube so as alternately to present the poles to different contiguous positions of the discharge, it will assume the form of ~ in consequence of its tendency to rotate round the poles in opposite directions, as the magnet in this position is moved up and down the side of the tube.

The effect is still more striking if the straight bar of a powerful electro-magnet is placed close to the ends of the stratifications; they then tend to rotate in one direction round the north, and in another round the south pole of the magnet.

45. If the mercury in apparatus (28.), fig. 7, is allowed to ascend so as to cover the negative wire, and thus produce a mercurial negative terminal, the action of the magnet on the stratifications will be found to be much heightened; as soon as the electro-magnet is excited, whether the polarity is north or south, the stratifications from the positive are violently drawn down the tube as an elongated spiral; under certain conditions they will assume the appearance of rotation, and if the magnet is such as to present north polarity to the discharge, the rotation is from right to left; if south, from left to right. I am aware that there is a difference of opinion as to the actual rotation of these bands, and that in many cases there is no evidence or even appearance of rotation; but under the influence of the magnet, as thus arranged, there cannot be any doubt as to the appearance being such as I have described. On the negative glow in this apparatus the magnet appears to have, in comparison with that on the positive discharge, a very slight effect, but it attracts or repels it according to the polarity of the magnet; it does not influence or produce any signs of stratification in the negative discharge.

46. When the discharge was first made in the pear-shaped apparatus, fig. 5 (24.), the mercury being negative and about 2 inches from the end of the positive wire, the discharge formed nearly a straight line; in this position, when the pole of a powerful electro-magnet was placed close to the glass vessel of the apparatus, the discharge was deflected across the pole at right angles, the discharge being from the positive wire to the negative mercury; if the magnet presented a northern polarity, the discharge deflected to the right, when looking from the magnet to the discharge, carrying with it the red spot in a direct line across the mercury.

47. When the discharge was made in the apparatus (fig. 6), the upper ball being

positive and the mercury negative, the tube was filled with brilliantly illuminated phosphorescent light. If, under this condition, a powerful magnet was presented to the light, the stratifications were drawn over and from the upper ball, while a minute spot of liquid mercury suspended from it was attracted and repelled according to the polarity of the magnet.

48. In this experiment I noticed another effect which I have not seen in any of my other apparatus. The magnet so divided the electrical discharge, that the rays producing the fluorescence in the glass tube were all accumulated in the neighbourhood of the negative terminal, the glass in that part being highly fluorescent, while the positive portion exhibited little or no signs of this phenomenon.

49. I refrain for the present from offering any observations as to the action of the magnet on the discharge. The intimate relation of magnetic and electric action has long since been shown; but the curious effect of the power of a magnet to draw out the stratification from the positive terminal (47.), and in some instances its powerful action on that portion of the discharge which exhibited the phosphorescent light in its greatest intensity (48.), are worthy of further examination. *In the preceding experiments my object was entirely directed to the examination of the stratified and the dark band discharge; at present I am inclined to the opinion that the stratifications in the positive, and the dark broad band between it and the negative glow, although apparently similar, are effects arising from distinct causes—the former from pulsations or impulses of a force acting on highly attenuated but a resisting medium, the latter from interference.* I am at this time engaged in making further experiments for the elucidation of this novel and remarkable phenomenon.

JOHN P. GASSIOT.

Clapham Common,
5 *January*, 1858.

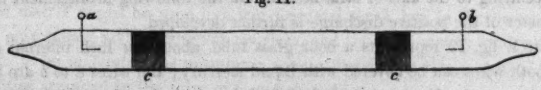
NOTE.—Received March 3,—Read March 4, 1858.

50. Shortly after presenting the preceding account of my experiments to the Royal Society, I had the pleasure of being introduced to Dr. ESSELBACH of Bonn, who informed me that M. GEISSLER of that city had recently constructed some vacuum tubes of great delicacy, and that an account of his experiments with RUHMKORFF'S inductive apparatus had been published in Germany. Through the kindness of Dr. BENCE JONES I have since procured several of the tubes from M. GEISSLER; their forms are varied, and show great skill in the construction, the stratifications from the inductive discharge being thus exhibited in a most beautiful and striking manner; but the complexity in the form of the apparatus renders these tubes to a great extent unsuitable for the careful examination of the phenomena. I have not as yet seen any publication of M. GEISSLER'S experiments, but I presume the tubes must have been constructed for a different object from what I have been pursuing, and for which I purposely had mine made in the most simple form I could devise.

51. Since the date of my paper I have made numerous experiments, some of which require further verification before they are published. I however avail myself of the opportunity afforded by the Council having appointed me to deliver the Bakerian Lecture, to submit the following for the consideration of the Royal Society.

52. Fig. 11 represents the vacuum tube that I now generally use; the vacuum is obtained by Mr. WELSH's process (20.); the tube is about 38 inches in length, the wires *a b* 32 inches apart; *cc'* are moveable coatings of tinfoil 2 inches long wrapped round the tube.

Fig. 11.



53. I have already stated that I obtained stratifications by the electrical machine (21.), and I have since ascertained that if a charged Leyden jar is discharged through a vacuum tube by means of a wet string, the stratifications are as large and as distinct as when taken from the induction coil.

54. When the discharges from an induction coil are made from wire to wire, the stratifications appear as already described (22.); and if the tube is placed in a horizontal position *over the pole of a magnet*, the stratifications evince a tendency to rotate as a whole in the direction of the well-known law of magnetic rotation; but when the discharge is made from coating to coating, or from one wire to one coating, an entirely new phenomenon arises: the stratifications have no longer a tendency to rotate as a whole, but are *divided*. If the tube is now placed *between* the poles of a powerful electro-magnet, one set of stratifications are repelled from, and the other attracted towards, or within the bent portion of the magnet; when the tube is placed on the north pole, the divided stratifications arrange themselves on each side of the tube, changing their respective positions when placed on the south pole, but in all cases each set of stratifications are concave in opposite directions.

55. If a vacuum tube, with or without wires or coatings, is placed on the induction coil in action, or on the prime conductor of an electrical machine, stratifications are discernible, and these can be divided by the magnet; the tube, after receiving discharges from the electrical machine, retains the charge for a short time; and if it is in this state laid on a table, flashes of light can be observed for several seconds, but gradually getting fainter and fainter.

56. Having thus ascertained that there are two distinct forms of the stratified electrical discharge, I propose, for the sake of clearness of expression, to designate them as the *direct* and the *induced* discharge. The direct discharge is that which is visible when taken from two wires hermetically sealed in a vacuum tube; this discharge has a tendency to rotate as a whole round the poles of a magnet; the induced discharge is that which is visible in the same vacuum when taken from two metallic coatings attached to the outside of the tube, or from one coating and one wire, or from one wire: one of my tubes has only one wire placed in its centre. The induced discharge is divisible by

the magnet into two sets of stratifications, each set having a tendency to rotate round the pole of the magnet in opposite directions: the character of the electrical discharge with relation to these two forms can always be determined by a magnet.

57. I have in all instances found that the discharge from the positive terminal exhibits a dominant action, as if the force issued from this direction. I have already alluded to the remarkable length (36.) of the column of stratifications, and I have given a drawing, Plate I. fig. 8, which I consider exhibits a direction of force from the positive to the negative, centring to the axis of stratification; in the following arrangement this dominant character of the positive discharge is further developed.

58. Plate I. fig. 12 represents a bent glass tube, about *one* inch internal diameter, in which both wires can be covered with liquid mercury; the wires *a* to *b* are 31 inches apart, from *a* to *c* the distance is 24 inches, from *b* to *d* 4 inches, from *d* to *c* 3 inches; by inclining the apparatus, the mercury from *a* can be elongated towards *c* to the length of 8 or 10 inches; in this condition, if *a* is negative, the entire surface of the mercury is covered with a brilliant white glow; if it is positive, the mercury is entirely luminous at the extreme end nearest *c*, but the remainder is unaffected by the discharge.

59. I cannot conclude this Note without expressing the deep sense of the obligation which I owe to Dr. FARADAY, who has, during the course of these investigations, not only afforded me the advantage of many important suggestions, but has also spared me much of his valuable time. I am at present continuing these most interesting experiments on the stratification, and should the results obtained be such as I anticipate, they will form the subject of a further communication.

J. P. G.

March 2, 1858.

II. *A Memoir on the Theory of Matrices.* By Arthur Cayley, *Esq.*, *F.R.S.*

Received December 10, 1857,—Read January 14, 1858.

The term matrix might be used in a more general sense, but in the present memoir I consider only square and rectangular matrices, and the term matrix used without qualification is to be understood as meaning a square matrix; in this restricted sense, a set of quantities arranged in the form of a square, *e. g.*

$$\begin{pmatrix} a, & b, & c \\ a', & b', & c' \\ a'', & b'', & c'' \end{pmatrix}$$

is said to be a matrix. The notion of such a matrix arises naturally from an abbreviated notation for a set of linear equations, viz. the equations

$$\begin{aligned} X &= ax + by + cz, \\ Y &= a'x + b'y + c'z, \\ Z &= a''x + b''y + c''z, \end{aligned}$$

may be more simply represented by

$$(X, Y, Z) = \begin{pmatrix} a, & b, & c \\ a', & b', & c' \\ a'', & b'', & c'' \end{pmatrix} (x, y, z),$$

and the consideration of such a system of equations leads to most of the fundamental notions in the theory of matrices. It will be seen that matrices (attending only to those of the same order) comport themselves as single quantities; they may be added, multiplied or compounded together, &c.: the law of the addition of matrices is precisely similar to that for the addition of ordinary algebraical quantities; as regards their multiplication (or composition), there is the peculiarity that matrices are not in general convertible; it is nevertheless possible to form the powers (positive or negative, integral or fractional) of a matrix, and thence to arrive at the notion of a rational and integral function, or generally of any algebraical function, of a matrix. I obtain the remarkable theorem that any matrix whatever satisfies an algebraical equation of its own order, the coefficient of the highest power being unity, and those of the other powers functions of the terms of the matrix, the last coefficient being in fact the determinant; the rule for the formation of this equation may be stated in the following condensed form, which will be intelligible after a perusal of the memoir, viz. the determi-

FRANKLIN INSTITUTE LIBRARY

nant, formed out of the matrix diminished by the matrix considered as a single quantity involving the matrix unity, will be equal to zero. The theorem shows that every rational and integral function (or indeed every rational function) of a matrix may be considered as a rational and integral function, the degree of which is at most equal to that of the matrix, less unity; it even shows that in a sense, the same is true with respect to any algebraical function whatever of a matrix. One of the applications of the theorem is the finding of the general expression of the matrices which are convertible with a given matrix. The theory of rectangular matrices appears much less important than that of square matrices, and I have not entered into it further than by showing how some of the notions applicable to these may be extended to rectangular matrices.

1. For conciseness, the matrices written down at full length will in general be of the order 3, but it is to be understood that the definitions, reasonings, and conclusions apply to matrices of any degree whatever. And when two or more matrices are spoken of in connexion with each other, it is always implied (unless the contrary is expressed) that the matrices are of the same order.

2. The notation

$$\left(\begin{array}{c|c} a\,,\ b\,,\ c & \\ a',\ b',\ c' & (x, y, z) \\ a'',\ b'',\ c'' & \end{array}\right)$$

represents the set of linear functions

$$\big((a, b, c)(x, y, z),\ (a', b', c')(x, y, z),\ (a'', b'', c'')(x, y, z)\big),$$

so that calling these (X, Y, Z), we have

$$(\mathrm{X}, \mathrm{Y}, \mathrm{Z}) \equiv \left(\begin{array}{c|c} a\,,\ b\,,\ c & \\ a',\ b',\ c' & (x, y, z) \\ a'',\ b'',\ c'' & \end{array}\right)$$

and, as remarked above, this formula leads to most of the fundamental notions in the theory.

3. The quantities (X, Y, Z) will be identically zero, if all the terms of the matrix are zero, and we may say that

$$\left(\begin{array}{c} 0,\ 0,\ 0 \\ 0,\ 0,\ 0 \\ 0,\ 0,\ 0 \end{array}\right)$$

is the matrix zero.

Again, (X, Y, Z) will be identically equal to (x, y, z), if the matrix is

$$\left(\begin{array}{c} 1,\ 0,\ 0 \\ 0,\ 1,\ 0 \\ 0,\ 0,\ 1 \end{array}\right)$$

and this is said to be the matrix unity. We may of course, when for distinctness it is

required, say, the matrix zero, or (as the case may be) the matrix unity *of such an order*. The matrix zero may for the most part be represented simply by 0, and the matrix unity by 1.

4. The equations

$$(X, Y, Z)=\left(\begin{array}{ccc} a, & b, & c \\ a', & b', & c' \\ a'', & b'', & c'' \end{array}\right)(x, y, z),\quad (X', Y', Z')=\left(\begin{array}{ccc} \alpha, & \beta, & \gamma \\ \alpha', & \beta', & \gamma' \\ \alpha'', & \beta'', & \gamma'' \end{array}\right)(x, y, z)$$

give

$$(X+X', Y+Y', Z+Z')=\left(\begin{array}{ccc} a+\alpha, & b+\beta, & c+\gamma \\ a'+\alpha', & b'+\beta', & c'+\gamma' \\ a''+\alpha'', & b''+\beta'', & c''+\gamma'' \end{array}\right)(x, y, z)$$

and this leads to

$$\left(\begin{array}{ccc} a+\alpha, & b+\beta, & c+\gamma \\ a'+\alpha', & b'+\beta', & c'+\gamma' \\ a''+\alpha'', & b''+\beta'', & c''+\gamma'' \end{array}\right)=\left(\begin{array}{ccc} a, & b, & c \\ a', & b', & c' \\ a'', & b'', & c'' \end{array}\right)+\left(\begin{array}{ccc} \alpha, & \beta, & \gamma \\ \alpha', & \beta', & \gamma' \\ \alpha'', & \beta'', & \gamma'' \end{array}\right)$$

as the rule for the addition of matrices; that for their subtraction is of course similar to it.

5. A matrix is not altered by the addition or subtraction of the matrix zero, that is, we have $M \pm 0 = M$.

The equation $L=M$, which expresses that the matrices L, M are equal, may also be written in the form $L-M=0$, *i. e.* the difference of two equal matrices is the matrix zero.

6. The equation $L=-M$, written in the form $L+M=0$, expresses that the sum of the matrices L, M is equal to the matrix zero, the matrices so related are said to be *opposite* to each other; in other words, a matrix the terms of which are equal but opposite in sign to the terms of a given matrix, is said to be opposite to the given matrix.

7. It is clear that we have $L+M=M+L$, that is, the operation of addition is commutative, and moreover that $(L+M)+N=L+(M+N)=L+M+N$, that is, the operation of addition is also associative.

8. The equation

$$(X, Y, Z)=\left(\begin{array}{ccc} a, & b, & c \\ a', & b', & c' \\ a'', & b'', & c'' \end{array}\right)(mx, my, mz)$$

written under the forms

$$(X, Y, Z)=m\left(\begin{array}{ccc} a, & b, & c \\ a', & b', & c' \\ a'', & b'', & c'' \end{array}\right)(x, y, z)=\left(\begin{array}{ccc} ma, & mb, & mc \\ ma', & mb', & mc' \\ ma'', & mb'', & mc'' \end{array}\right)(x, y, z)$$

gives

$$m\begin{pmatrix} a, & b, & c \\ a', & b', & c' \\ a'', & b'', & c'' \end{pmatrix}=\begin{pmatrix} ma, & mb, & mc \\ ma', & mb', & mc' \\ ma'', & mb'', & mc'' \end{pmatrix}$$

as the rule for the multiplication of a matrix by a single quantity. The multiplier m may be written either before or after the matrix, and the operation is therefore commutative. We have it is clear $m(\mathrm{L}+\mathrm{M})=m\mathrm{L}+m\mathrm{M}$, or the operation is distributive.

9. The matrices L and mL may be said to be similar to each other; in particular, if $m=1$, they are equal, and if $m=-1$, they are opposite.

10. We have, in particular,

$$m\begin{pmatrix} 1, & 0, & 0 \\ 0, & 1, & 0 \\ 0, & 0, & 1 \end{pmatrix}=\begin{pmatrix} m, & 0, & 0 \\ 0, & m, & 0 \\ 0, & 0, & m \end{pmatrix},$$

or replacing the matrix on the left-hand side by unity, we may write

$$m=\begin{pmatrix} m, & 0, & 0 \\ 0, & m, & 0 \\ 0, & 0, & m \end{pmatrix},$$

The matrix on the right-hand side is said to be the single quantity m considered as *involving the matrix unity*.

11. The equations

$$(\mathrm{X}, \mathrm{Y}, \mathrm{Z})=\begin{pmatrix} a, & b, & c \\ a', & b', & c' \\ a'', & b'', & c'' \end{pmatrix}(x, y, z), \quad (x, y, z)=\begin{pmatrix} \alpha, & \beta, & \gamma \\ \alpha', & \beta', & \gamma' \\ \alpha'', & \beta'', & \gamma'' \end{pmatrix}(\xi, \eta, \zeta),$$

give

$$(\mathrm{X}, \mathrm{Y}, \mathrm{Z})=\begin{pmatrix} \mathrm{A}, & \mathrm{B}, & \mathrm{C} \\ \mathrm{A}', & \mathrm{B}', & \mathrm{C}' \\ \mathrm{A}'', & \mathrm{B}'', & \mathrm{C}'' \end{pmatrix}(\xi, \eta, \zeta)=\begin{pmatrix} a, & b, & c \\ a', & b', & c' \\ a'', & b'', & c'' \end{pmatrix}\begin{pmatrix} \alpha, & \beta, & \gamma \\ \alpha', & \beta', & \gamma' \\ \alpha'', & \beta'', & \gamma'' \end{pmatrix}(\xi, \eta, \zeta),$$

and thence, substituting for the matrix

$$\begin{pmatrix} \mathrm{A}, & \mathrm{B}, & \mathrm{C} \\ \mathrm{A}', & \mathrm{B}', & \mathrm{C}' \\ \mathrm{A}'', & \mathrm{B}'', & \mathrm{C}'' \end{pmatrix}$$

its value, we obtain

$$\begin{pmatrix} (a, b, c)(\alpha, \alpha', \alpha''), & (a, b, c)(\beta, \beta', \beta''), & (a, b, c)(\gamma, \gamma', \gamma'') \\ (a', b', c')(\alpha, \alpha', \alpha''), & (a', b', c')(\beta, \beta', \beta''), & (a', b', c')(\gamma, \gamma', \gamma'') \\ (a'', b'', c'')(\alpha, \alpha', \alpha''), & (a'', b'', c'')(\beta, \beta', \beta''), & (a'', b'', c'')(\gamma, \gamma', \gamma'') \end{pmatrix}=\begin{pmatrix} a, & b, & c \\ a', & b', & c' \\ a'', & b'', & c'' \end{pmatrix}\begin{pmatrix} \alpha, & \beta, & \gamma \\ \alpha', & \beta', & \gamma' \\ \alpha'', & \beta'', & \gamma'' \end{pmatrix}$$

as the rule for the multiplication or composition of two matrices. It is to be observed, that the operation is not a commutative one; the component matrices may be distinguished as the first or further component matrix, and the second or nearer component matrix, and the rule of composition is as follows, viz. any *line* of the compound matrix is obtained by combining the corresponding *line* of the first or further component matrix successively with the several *columns* of the second or nearer compound matrix.

12. A matrix compounded, either as first or second component matrix, with the matrix zero, gives the matrix zero. The case where any of the terms of the given matrix are infinite is of course excluded.

13. A matrix is not altered by its composition, either as first or second component matrix, with the matrix unity. It is compounded either as first or second component matrix, with the single quantity m considered as involving the matrix unity, by multiplication of all its terms by the quantity m: this is in fact the before-mentioned rule for the multiplication of a matrix by a single quantity, which rule is thus seen to be a particular case of that for the multiplication of two matrices.

14. We may in like manner multiply or compound together three or more matrices: the order of arrangement of the factors is of course material, and we may distinguish them as the first or furthest, second, third, &c., and last or nearest component matrices, but any two consecutive factors may be compounded together and replaced by a single matrix, and so on until all the matrices are compounded together, the result being independent of the particular mode in which the composition is effected; that is, we have $\mathrm{L.MN=LM.N=LMN}$, $\mathrm{LM.NP=L.MN.P}$, &c., or the operation of multiplication, although, as already remarked, not commutative, is associative.

15. We thus arrive at the notion of a positive and integer power L^p of a matrix L, and it is to be observed that the different powers of the same matrix are convertible. It is clear also that p and q being positive integers, we have $\mathrm{L}^p.\mathrm{L}^q=\mathrm{L}^{p+q}$, which is the theorem of indices for positive integer powers of a matrix.

16. The last-mentioned equation, $\mathrm{L}^p.\mathrm{L}^q=\mathrm{L}^{p+q}$, assumed to be true for all values whatever of the indices p and q, leads to the notion of the powers of a matrix for any form whatever of the index. In particular, $\mathrm{L}^p.\mathrm{L}^0=\mathrm{L}^p$ or $\mathrm{L}^0=1$, that is, the 0th power of a matrix is the matrix unity. And then putting $p=1$, $q=-1$, or $p=-1$, $q=1$, we have $\mathrm{L.L}^{-1}=\mathrm{L}^{-1}.\mathrm{L}=1$; that is, L^{-1}, or as it may be termed the inverse or reciprocal matrix, is a matrix which, compounded either as first or second component matrix with the original matrix, gives the matrix unity.

17. We may arrive at the notion of the inverse or reciprocal matrix, directly from the equation

$$(\mathrm{X}, \mathrm{Y}, \mathrm{Z})=\begin{pmatrix} a\,, & b\,, & c \\ a', & b', & c' \\ a'', & b'', & c'' \end{pmatrix}(x, y, z),$$

in fact this equation gives

$$(x, y, z)=\begin{pmatrix} A, & A', & A'' \\ B, & B', & B'' \\ C, & C', & C'' \end{pmatrix}(X, Y, Z)=\left(\begin{pmatrix} a, & b, & c \\ a', & b', & c' \\ a'', & b'', & c'' \end{pmatrix}\right)^{-1}(X, Y, Z),$$

and we have, for the determination of the coefficients of the inverse or reciprocal matrix, the equations

$$\begin{pmatrix} A, & A', & A'' \\ B, & B', & B'' \\ C, & C', & C'' \end{pmatrix}\begin{pmatrix} a, & b, & c \\ a', & b', & c' \\ a'', & b'', & c'' \end{pmatrix}=\begin{pmatrix} 1, & 0, & 0 \\ 0, & 1, & 0 \\ 0, & 0, & 1 \end{pmatrix},$$

$$\begin{pmatrix} a, & b, & c \\ a', & b', & c' \\ a'', & b'', & c'' \end{pmatrix}\begin{pmatrix} A, & A', & A'' \\ B, & B', & B'' \\ C, & C', & C'' \end{pmatrix}=\begin{pmatrix} 1, & 0, & 0 \\ 0, & 1, & 0 \\ 0, & 0, & 1 \end{pmatrix},$$

which are equivalent to each other, and either of them is by itself sufficient for the complete determination of the inverse or reciprocal matrix. It is well known that if ∇ denote the determinant, that is, if

$$\nabla=\begin{vmatrix} a, & b, & c \\ a', & b', & c' \\ a'', & b'', & c'' \end{vmatrix}$$

then the terms of the inverse or reciprocal matrix are given by the equations

$$A=\frac{1}{\nabla}\begin{vmatrix} 1, & 0, & 0 \\ 0, & b', & c' \\ 0, & b'', & c'' \end{vmatrix}, \qquad B=\frac{1}{\nabla}\begin{vmatrix} 0, & 1, & 0 \\ a', & 0, & c' \\ a'', & 0, & c'' \end{vmatrix}, \text{ \&c.}$$

or what is the same thing, the inverse or reciprocal matrix is given by the equation

$$\begin{pmatrix} a, & b, & c \\ a', & b', & c' \\ a'', & b'', & c'' \end{pmatrix}^{-1}=\frac{1}{\nabla}\begin{pmatrix} \partial_a\nabla, & \partial_{a'}\nabla, & \partial_{a''}\nabla \\ \partial_b\nabla, & \partial_{b'}\nabla, & \partial_{b''}\nabla \\ \partial_c\nabla, & \partial_{c'}\nabla, & \partial_{c''}\nabla \end{pmatrix}.$$

where of course the differentiations must in every case be performed as if the terms a, b, &c. were all of them independent arbitrary quantities.

18. The formula shows, what is indeed clear *à priori*, that the notion of the inverse or reciprocal matrix fails altogether when the determinant vanishes: the matrix is in this case said to be indeterminate, and it must be understood that in the absence of express mention, the particular case in question is frequently excluded from consideration. It may be added that the matrix zero is indeterminate; and that the product of two matrices may be zero, without either of the factors being zero, if only the matrices are one or both of them indeterminate.

19. The notion of the inverse or reciprocal matrix once established, the other negative integer powers of the original matrix are positive integer powers of the inverse or reciprocal matrix, and the theory of such negative integer powers may be taken to be known. The further discussion of the fractional powers of a matrix will be resumed in the sequel.

20. The positive integer power L^m of the matrix L may of course be multiplied by any matrix of the same degree, such multiplier, however, is not in general convertible with L; and to preserve as far as possible the analogy with ordinary algebraical functions, we may restrict the attention to the case where the multiplier is a single quantity, and such convertibility consequently exists. We have in this manner a matrix cL^m, and by the addition of any number of such terms we obtain a rational and integral function of the matrix L.

21. The general theorem before referred to will be best understood by a complete development of a particular case. Imagine a matrix

$$M=\begin{pmatrix} a, & b \\ c, & d \end{pmatrix},$$

and form the determinant

$$\begin{vmatrix} a-M, & b \\ c, & d-M \end{vmatrix},$$

the developed expression of this determinant is

$$M^2-(a+d)M^1+(ad-bc)M^0;$$

the values of M^2, M^1, M^0 are

$$\begin{pmatrix} a^2+bc, & b(a+d) \\ c(a+d), & d^2+bc \end{pmatrix}, \quad \begin{pmatrix} a, & b \\ c, & d \end{pmatrix}, \quad \begin{pmatrix} 1, & 0 \\ 0, & 1 \end{pmatrix},$$

and substituting these values the determinant becomes equal to the matrix zero, viz. we have

$$\begin{vmatrix} a-M, & b \\ c, & d-M \end{vmatrix}=\begin{pmatrix} a^2+bc, & b(a+d) \\ c(a+d), & d^2+bc \end{pmatrix}-(a+d)\begin{pmatrix} a, & b \\ c, & d \end{pmatrix}+(ad-bc)\begin{pmatrix} 1, & 0 \\ 0, & 1 \end{pmatrix}$$

$$=\begin{pmatrix} (a^2+bc)-(a+d)a+(ad-bc), & b(a+d)-(a+d)b \\ c(a+d)-(a+d)c, & d^2+bc-(a+d)d+ad-bc \end{pmatrix}=\begin{pmatrix} 0, & 0 \\ 0, & 0 \end{pmatrix}.$$

that is,

$$\begin{vmatrix} a-M, & b \\ c, & d-M \end{vmatrix}=0$$

where the matrix of the determinant is

$$\begin{pmatrix} a, & b \\ c, & d \end{pmatrix}-M\begin{pmatrix} 1, & 0 \\ 0, & 1 \end{pmatrix},$$

that is, it is the original matrix, diminished by the same matrix considered as a single

quantity involving the matrix unity. And this is the general theorem, viz. the determinant, having for its matrix a given matrix less the same matrix considered as a single quantity involving the matrix unity, is equal to zero.

22. The following symbolical representation of the theorem is, I think, worth noticing: let the matrix M, considered as a single quantity, be represented by $\tilde{\mathrm{M}}$, then writing 1 to denote the matrix unity, $\tilde{\mathrm{M}}.1$ will represent the matrix M, considered as a single quantity involving the matrix unity. Upon the like principles of notation, $\tilde{1}.\mathrm{M}$ will represent, or may be considered as representing, simply the matrix M, and the theorem is

$$\mathrm{Det.}\,(\tilde{1}.\mathrm{M}-\tilde{\mathrm{M}}.1)=0.$$

23. I have verified the theorem, in the next simplest case, of a matrix of the order 3, viz. if M be such a matrix, suppose

$$\mathrm{M}=\begin{pmatrix} a, & b, & c \\ d, & e, & f \\ g, & h, & i \end{pmatrix},$$

then the derived determinant vanishes, or we have

$$\begin{vmatrix} a-\mathrm{M}, & b & , c \\ d & , e-\mathrm{M}, & f \\ g & , h & , i-\mathrm{M} \end{vmatrix}=0,$$

or expanding,

$$\mathrm{M}^3-(a+e+i)\mathrm{M}^2+(ei+ia+ae-fh-cg-bd)\mathrm{M}-(aei+bfg+cdh-afh-bdi-ceg)=0;$$

but I have not thought it necessary to undertake the labour of a formal proof of the theorem in the general case of a matrix of any degree.

24. If we attend only to the general form of the result, we see that any matrix whatever satisfies an algebraical equation of its own order, which is in many cases the material part of the theorem.

25. It follows at once that every rational and integral function, or indeed every rational function of a matrix, can be expressed as a rational and integral function of an order at most equal to that of the matrix, less unity. But it is important to consider how far or in what sense the like theorem is true with respect to irrational functions of a matrix. If we had only the equation satisfied by the matrix itself, such extension could not be made; but we have besides the equation of the same order satisfied by the irrational function of the matrix, and by means of these two equations, and the equation by which the irrational function of the matrix is determined, we may express the irrational function as a rational and integral function of the matrix, of an order equal at most to that of the matrix, less unity; such expression will however involve *the coefficients of the equation satisfied by the irrational function* which are functions (in number equal to the order of the matrix) of the coefficients assumed unknown, of the irrational function itself. The transformation is nevertheless an important one, as reducing the

number of unknown quantities from n^2 (if n be the order of the matrix) down to n. To complete the solution, it is necessary to compare the value obtained as above, with the assumed value of the irrational function, which will lead to equations for the determination of the n unknown quantities.

26. As an illustration, consider the given matrix

$$M=\begin{pmatrix} a, & b \\ c, & d \end{pmatrix}$$

and let it be required to find the matrix $L=\sqrt{M}$. In this case M satisfies the equation

$$M^2-(a+d)M+ad-bc=0;$$

and in like manner if

$$L=\begin{pmatrix} \alpha, & \beta \\ \gamma, & \delta \end{pmatrix}$$

then L satisfies the equation

$$L^2-(\alpha+\delta)L+\alpha\delta-\beta\gamma=0;$$

and from these two equations, and the rationalized equation $L^2=M$, it should be possible to express L in the form of a linear function of M: in fact, putting in the last equation for L^2 its value $(=M)$, we find at once

$$L=\frac{1}{\alpha+\delta}[M+(\alpha\delta-\beta\gamma)],$$

which is the required expression, involving as it should do the coefficients $\alpha+\delta$, $\alpha\delta-\beta\gamma$ of the equation in L. There is no difficulty in completing the solution; write for shortness $\alpha+\delta=X$, $\alpha\delta-\beta\gamma=Y$, then we have

$$L=\begin{pmatrix} \alpha, & \beta \\ \gamma, & \delta \end{pmatrix}=\begin{pmatrix} \frac{a+Y}{X}, & \frac{b}{X} \\ \frac{c}{X}, & \frac{d+Y}{X} \end{pmatrix},$$

and consequently forming the values of $\alpha+\delta$ and $\alpha\delta-\beta\gamma$,

$$X=\frac{a+d+2Y}{X},$$

$$Y=\frac{(a+Y)(d+Y)-bc}{X^2},$$

and putting also $a+d=P$, $ad-bc=Q$, we find without difficulty

$$X=\sqrt{P+2\sqrt{Q}},$$

$$Y=\sqrt{Q},$$

and the values of α, β, γ, δ are consequently known. The sign of $\sqrt{Q}$ is the same in both formulæ, and there are consequently in all four solutions, that is, the radical $\sqrt{M}$ has four values.

FRANKLIN INSTITUTE LIBRARY.

27. To illustrate this further, suppose that instead of M we have the matrix

$$M^2=\begin{pmatrix} a, & b \\ c, & d \end{pmatrix}^2=\begin{pmatrix} a^2+bc\ , & b(a+d) \\ c(a+d), & d^2+bc \end{pmatrix},$$

so that $L^2=M^2$, we find

$$P=(a+d)^2-2(ad-bc),$$
$$Q=(ad-bc)^2,$$

and thence $\sqrt{Q}=\pm(ad-bc)$. Taking the positive sign, we have

$$Y=ad-bc,$$
$$X=\pm(a+d),$$

and these values give simply

$$L=\pm\begin{pmatrix} a, & b \\ c, & d \end{pmatrix}=\pm M,$$

But taking the negative sign,

$$Y=-ad+bc,$$
$$X=\pm\sqrt{(a-d)^2+4bc},$$

and retaining X to denote this radical, we find

$$L=\begin{pmatrix} \dfrac{a^2-ad+2bc}{X}, & \dfrac{b(a+d)}{X} \\ \dfrac{c(a+d)}{X}\ , & \dfrac{d^2-ad+2bc}{X} \end{pmatrix},$$

which may also be written

$$L=\frac{a+d}{X}\begin{pmatrix} a, & b \\ c, & d \end{pmatrix}-\frac{2(ad-bc)}{X}\begin{pmatrix} 1, & 0 \\ 0, & 1 \end{pmatrix},$$

or, what is the same thing,

$$L=\frac{a+d}{X}M-\frac{2(ad-bc)}{X};$$

and it is easy to verify *à posteriori* that this value in fact gives $L^2=M^2$. It may be remarked that if

$$M^2=\begin{pmatrix} 1, & 0 \\ 0, & 1 \end{pmatrix}^2=1,$$

the last-mentioned formula fails, for we have $X=0$; it will be seen presently that the equation $L^2=1$ admits of other solutions besides $L=\pm 1$. The example shows how the values of the fractional powers of a matrix are to be investigated.

28. There is an apparent difficulty connected with the equation satisfied by a matrix, which it is proper to explain. Suppose, as before,

$$M=\begin{pmatrix} a, & b \\ c, & d \end{pmatrix},$$

so that M satisfies the equation

$$\begin{vmatrix} a-\mathrm{M}, & b \\ c & , d-\mathrm{M} \end{vmatrix}=0,$$

or

$$\mathrm{M}^2-(a+d)\mathrm{M}+ad-bc=0,$$

and let $\mathrm{X}_{\prime}$, $\mathrm{X}_{\prime\prime}$ be the single quantities, roots of the equation

$$\begin{vmatrix} a-\mathrm{X}, & b \\ c & , d-\mathrm{X} \end{vmatrix}=0$$

or

$$\mathrm{X}^2-(a+d)\mathrm{X}+ad-bc=0.$$

The equation satisfied by the matrix may be written

$$(\mathrm{M}-\mathrm{X}_{\prime})(\mathrm{M}-\mathrm{X}_{\prime\prime})=0,$$

in which $\mathrm{X}_{\prime}$, $\mathrm{X}_{\prime\prime}$ are to be considered as respectively involving the matrix unity, and it would at first sight seem that we ought to have one of the simple factors equal to zero, which is obviously not the case, for such equation would signify that the perfectly indeterminate matrix M was equal to a single quantity, considered as involving the matrix unity. The explanation is that each of the simple factors is an indeterminate matrix, in fact $\mathrm{M}-\mathrm{X}_{\prime}$ stands for the matrix

$$\begin{pmatrix} a-\mathrm{X}_{\prime}, & b \\ c & , d-\mathrm{X}_{\prime} \end{pmatrix},$$

and the determinant of this matrix is equal to zero. The product of the two factors is thus equal to zero without either of the factors being equal to zero.

29. A matrix satisfies, we have seen, an equation of its own order, involving the coefficients of the matrix; assume that the matrix is to be determined to satisfy some other equation, the coefficients of which are given single quantities. It would at first sight appear that we might eliminate the matrix between the two equations, and thus obtain an equation which would be the only condition to be satisfied by the terms of the matrix; this is obviously wrong, for more conditions must be requisite, and we see that if we were then to proceed to complete the solution by finding the value of the matrix common to the two equations, we should find the matrix equal in every case to a single quantity considered as involving the matrix unity, which it is clear ought not to be the case. The explanation is similar to that of the difficulty before adverted to, the equations may contain one, and only one, common factor, and may be both of them satisfied, and yet the common factor may not vanish. The necessary condition seems to be, that the one equation should be a factor of the other; in the case where the assumed equation is of an order equal or superior to the matrix, then if this equation contain as a factor the equation which is always satisfied by the matrix, the assumed equation will be satisfied identically, and the condition is sufficient as well as necessary:

in the other case, where the assumed equation is of an order inferior to that of the matrix, the condition is necessary, but it is not sufficient.

30. The equation satisfied by the matrix may be of the form $M^n=1$; the matrix is in this case said to be periodic of the nth order. The preceding considerations apply to the theory of periodic matrices; thus, for instance, suppose it is required to find a matrix of the order 2, which is periodic of the second order. Writing

$$M=\begin{pmatrix} a, & b \\ c, & d \end{pmatrix},$$

we have

$$M^2-(a+d)M+ad-bc=0,$$

and the assumed equation is

$$M^2-1=0.$$

These equations will be identical if

$$a+d=0,\ ad-bc=-1,$$

that is, these conditions being satisfied, the equation $M^2-1=0$ required to be satisfied, will be identical with the equation which is always satisfied, and will therefore itself be satisfied. And in like manner the matrix M of the order 2 will satisfy the condition $M^3-1=0$, or will be periodic of the third order, if only M^3-1 contains as a factor

$$M^2-(a+d)M+ad-bc,$$

and so on.

31. But suppose it is required to find a matrix of the order 3,

$$M=\begin{pmatrix} a, & b, & c \\ d, & e, & f \\ g, & h, & i \end{pmatrix}$$

which shall be periodic of the second order. Writing for shortness

$$\begin{vmatrix} a-M, & b & , c \\ d & , e-M, & f \\ g & , h & , i-M \end{vmatrix}=-(M^3-AM^2+BM-C),$$

the matrix here satisfies

$$M^3-AM^2+BM-C=0,$$

and, as before, the assumed equation is $M^3-1=0$. Here, if we have $1+B=0$, $A+C=0$, the left-hand side will contain the factor (M^3-1), and the equation will take the form $(M^3-1)(M+C)=0$, and we should have then $M^3-1=0$, provided $M+C$ were not an indeterminate matrix. But $M+C$ denotes the matrix

$$\begin{pmatrix} a+C, & b & , c \\ d & , e+C, & f \\ g & , h & , i+C \end{pmatrix}$$

the determinant of which is C^3+AC^2+BC+C, which is equal to zero in virtue of

the equations $1+B=0$, $A+C=0$, and we cannot, therefore, from the equation $(M^2-1)(M+C)=0$, deduce the equation $M^3-1=0$. This is as it should be, for the two conditions are not sufficient, in fact the equation

$$M^2=\begin{pmatrix} a^2+bd+cg, & ab+be+ch, & ac+bf+ci \\ da+ed+fg, & db+e^2+fh, & dc+ef+fi \\ ga+hd+ig, & gb+he+ih, & gc+hf+i^2 \end{pmatrix}=1$$

gives nine equations, which are however satisfied by the following values, involving in reality four arbitrary coefficients; viz. the value of the matrix is

$$k=\begin{pmatrix} \frac{\alpha}{\alpha+\beta+\gamma}, & \frac{-(\beta+\gamma)\frac{\nu}{\mu}}{\alpha+\beta+\gamma}, & \frac{-(\beta+\gamma)\frac{\nu}{\mu}}{\alpha+\beta+\gamma} \\ \frac{-(\gamma+\alpha)\mu\nu^{-1}}{\alpha+\beta+\gamma}, & \frac{\beta}{\alpha+\beta+\gamma}, & \frac{-(\gamma+\alpha)\frac{\lambda}{\mu}}{\alpha+\beta+\gamma} \\ \frac{-(\alpha+\beta)\mu\nu^{-1}}{\alpha+\beta+\gamma}, & \frac{-(\alpha+\beta)\frac{\nu}{\lambda}}{\alpha+\beta+\gamma}, & \frac{\gamma}{\alpha+\beta+\gamma} \end{pmatrix}$$

so that there are in all four relations (and not only two) between the coefficients of the matrix.

32. Instead of the equation $M^n-1=0$, which belongs to a periodic matrix, it is in many cases more convenient, and it is much the same thing to consider an equation $M^n-k=0$, where k is a single quantity. The matrix may in this case be said to be periodic to a factor *près*.

33. Two matrices L, M are convertible when $LM=ML$. If the matrix M is given, this equality affords a set of linear equations between the coefficients of L equal in number to these coefficients, but these equations cannot be all independent, for it is clear that if L be any rational and integral function of M (the coefficients being single quantities), then L will be convertible with M; or what is apparently (but only apparently) more general, if L be any algebraical function whatever of M (the coefficients being always single quantities), then L will be convertible with M. But whatever the form of the function is, it may be reduced to a rational and integral function of an order equal to that of M, less unity, and we have thus the general expression for the matrices convertible with a given matrix, viz. any such matrix is a rational and integral function (the coefficients being single quantities) of the given matrix, the order being that of the given matrix, less unity. In particular, the general form of the matrix L convertible with a given matrix M of the order 2, is $L=\alpha M+\beta$, or what is the same thing, the matrices

$$\begin{pmatrix} a, & b \\ c, & d \end{pmatrix}, \quad \begin{pmatrix} a', & b' \\ c', & d' \end{pmatrix}$$

will be convertible if $a'-d' : b' : c'=a-d : b : c$.

34. Two matrices L, M are skew convertible when $LM=-ML$; this is a relation much less important than ordinary convertibility, for it is to be noticed that we cannot in general find a matrix L skew convertible with a given matrix M. In fact, considering M as given, the equality affords a set of linear equations between the coefficients of L equal in number to these coefficients; and in this case the equations are independent, and we may eliminate all the coefficients of L, and we thus arrive at a relation which must be satisfied by the coefficients of the given matrix M. Thus, suppose the matrices

$$\begin{pmatrix} a, & b \\ c, & d \end{pmatrix}, \begin{pmatrix} a', & b' \\ c', & d' \end{pmatrix}$$

are skew convertible, we have

$$\begin{pmatrix} a, & b \\ c, & d \end{pmatrix}\begin{pmatrix} a', & b' \\ c', & d' \end{pmatrix}=\begin{pmatrix} aa'+bc', & ab'+bd' \\ ca'+dc', & cb'+dd' \end{pmatrix},$$

$$\begin{pmatrix} a', & b' \\ c', & d' \end{pmatrix}\begin{pmatrix} a, & b \\ c, & d \end{pmatrix}=\begin{pmatrix} aa'+b'c, & a'b+b'd \\ c'a+d'c, & c'b+d'd \end{pmatrix},$$

and the conditions of skew convertibility are

$$\begin{aligned} 2aa'+bc'+b'c &=0 \\ b'(a+d)+b(a'+d') &=0 \\ c'(a+d)+c(a'+d') &=0 \\ 2dd'+bc'+b'c &=0 \end{aligned}$$

Eliminating a', b', c', d', the relation between a, b, c, d is

$$\begin{vmatrix} 2a, & c\ , & b\ , & . \\ b\ , & a+d, & . & b \\ c\ , & . & a+d, & c \\ . & c\ , & b\ , & 2d \end{vmatrix}=0.$$

which is

$$(a+d)^2(ad-bc)=0.$$

Excluding from consideration the case $ad-bc=0$, which would imply that the matrix was indeterminate, we have $a+d=0$. The resulting system of conditions then is

$$a+d=0,\quad a'+d'=0,\quad aa'+bc'+b'c+dd'=0,$$

the first two of which imply that the matrices are respectively periodic of the second order to a factor *près*.

35. It may be noticed that if the compound matrices LM and ML are similar, they are either equal or else opposite; that is, the matrices L, M are either convertible or skew convertible.

36. Two matrices such as

$$\begin{pmatrix} a, & b \\ c, & d \end{pmatrix}, \quad \begin{pmatrix} a, & c \\ b, & d \end{pmatrix},$$

are said to be formed one from the other by transposition, and this may be denoted by the symbol tr.; thus we may write

$$\begin{pmatrix} a, & c \\ b, & d \end{pmatrix} = \text{tr.} \begin{pmatrix} a, & b \\ c, & d \end{pmatrix},$$

The effect of two successive transpositions is of course to reproduce the original matrix.

37. It is easy to see that if M be any matrix, then

$$(\text{tr. M})^p = \text{tr. } (\text{M}^p),$$

and in particular,

$$(\text{tr. M})^{-1} = \text{tr. } (\text{M}^{-1}).$$

38. If L, M be any two matrices,

$$\text{tr. } (\text{LM}) = \text{tr. M. } \text{ tr. L},$$

and similarly for three or more matrices, L, M, N, &c.,

$$\text{tr. } (\text{LMN}) = \text{tr. N. } \text{ tr. M. } \text{ tr. L, \&c.}$$

40. A matrix such as

$$\begin{pmatrix} a, & h, & g \\ h, & b, & f \\ g, & f, & c \end{pmatrix}$$

which is not altered by transposition, is said to be symmetrical.

41. A matrix such as

$$\begin{pmatrix} 0, & \nu, & -\mu \\ -\nu, & 0, & \lambda \\ \mu, & -\lambda, & 0 \end{pmatrix}$$

which by transposition is changed into its opposite, is said to be skew symmetrical.

42. It is easy to see that any matrix whatever may be expressed as the sum of a symmetrical matrix, and a skew symmetrical matrix; thus the form

$$\begin{pmatrix} a\ , & h+\nu, & g-\mu \\ h-\nu, & b\ , & f+\lambda \\ g+\mu, & f-\lambda, & c \end{pmatrix}$$

which may obviously represent any matrix whatever of the order 3, is the sum of the two matrices last before mentioned.

43. The following formulæ, although little more than examples of the composition of transposed matrices, may be noticed, viz.

$$\begin{pmatrix} a, & b \\ c, & d \end{pmatrix} \begin{pmatrix} a, & c \\ d, & b \end{pmatrix} = \begin{pmatrix} a^2+b^2\ , & ac+bd \\ ac+bd, & c^2+d^2 \end{pmatrix}$$

which shows that a matrix compounded with the transposed matrix gives rise to a symmetrical matrix. It does not however follow, nor is it the fact, that the matrix and transposed matrix are convertible. And also

$$\begin{pmatrix} a, & c \\ b, & d \end{pmatrix}\begin{pmatrix} a, & b \\ c, & d \end{pmatrix}\begin{pmatrix} a, & c \\ b, & d \end{pmatrix}=\begin{pmatrix} a^3+bcd+a(b^2+c^2), & c^3+abd+c(a^2+d^2) \\ b^3+acd+b(a^2+d^2), & d^3+abc+d(b^2+c^2) \end{pmatrix}$$

which is a remarkably symmetrical form. It is needless to proceed further, since it is clear that

$$\begin{pmatrix} a, & c \\ b, & d \end{pmatrix}\begin{pmatrix} a, & b \\ c, & d \end{pmatrix}\begin{pmatrix} a, & c \\ b, & d \end{pmatrix}\begin{pmatrix} a, & b \\ c, & d \end{pmatrix}=\left(\begin{pmatrix} a, & c \\ b, & d \end{pmatrix}\begin{pmatrix} a, & b \\ c, & d \end{pmatrix}\right)^2$$

44. In all that precedes, the matrix of the order 2 has frequently been considered, but chiefly by way of illustration of the general theory; but it is worth while to develope more particularly the theory of such matrix. I call to mind the fundamental properties which have been obtained, viz. it was shown that the matrix

$$\mathrm{M}=\begin{pmatrix} a, & b \\ c, & d \end{pmatrix},$$

satisfies the equation

$$\mathrm{M}^2-(a+d)\mathrm{M}+ad-bc=0,$$

and that the two matrices

$$\begin{pmatrix} a, & b \\ c, & d \end{pmatrix},\quad \begin{pmatrix} a', & b' \\ c', & d' \end{pmatrix},$$

will be convertible if

$$a'-d' : b' : c'=a-d : b : c,$$

and that they will be skew convertible if

$$a+d=0,\quad a'+d'=0,\quad aa'+bc'+b'c+dd'=0,$$

the first two of these equations being the conditions in order that the two matrices may be respectively periodic of the second order to a factor *près*.

45. It may be noticed in passing, that if L, M are skew convertible matrices of the order 2, and if these matrices are also such that $\mathrm{L}^2=-1$, $\mathrm{M}^2=-1$, then putting $\mathrm{N}=\mathrm{LM}=-\mathrm{ML}$, we obtain

$$\mathrm{L}^2=-1,\quad \mathrm{M}^2=-1,\quad \mathrm{N}^2=-1,$$

$$\mathrm{L}=\mathrm{MN}=-\mathrm{NM},\quad \mathrm{M}=\mathrm{NL}=-\mathrm{NL},\quad \mathrm{N}=\mathrm{LM}=-\mathrm{ML},$$

which is a system of relations precisely similar to that in the theory of quaternions.

46. The integer powers of the matrix

$$\mathrm{M}=\begin{pmatrix} a, & b \\ c, & d \end{pmatrix},$$

are obtained with great facility from the quadratic equation; thus we have, attending first to the positive powers,

$$M^2=(a+d)M-(ad-bc),$$
$$M^3=[(a+d)^2-(ad-bc)]M-(a+d)(ad-bc),$$
&c.,

whence also the conditions in order that the matrix may be to a factor *près* periodic of the orders 2, 3, &c. are

$$a+d \qquad\qquad =0,$$
$$(a+d)^2-(ad-bc)=0,$$
&c.;

and for the negative powers we have

$$(ad-bc)M^{-1}=-M+(a+d),$$

which is equivalent to the ordinary form

$$(ad-bc)M^{-1}=\begin{pmatrix} d, & -b \\ -c, & a \end{pmatrix};$$

and the other negative powers of M can then be obtained by successive multiplications with M^{-1}.

47. The expression for the nth power is however most readily obtained by means of a particular algorithm for matrices of the order 2.

Let h, b, c, J, q be any quantities, and write for shortness $R=-h^2-4bc$; suppose also that h', b', c', J', q' are any other quantities, such nevertheless that $h':b':c'=h:b:c$, and write in like manner $R'=-h'^2-4b'c'$. Then observing that $\frac{h}{\sqrt{R}}$, $\frac{b}{\sqrt{R}}$, $\frac{c}{\sqrt{R}}$ are respectively equal to $\frac{h'}{\sqrt{R'}}$, $\frac{b'}{\sqrt{R'}}$, $\frac{c'}{\sqrt{R'}}$, the matrix

$$\begin{pmatrix} J\left(\cot q-\frac{h}{\sqrt{R}}\right), & \frac{2bJ}{\sqrt{R}} \\ \frac{2cJ}{\sqrt{R}}, & J\left(\cot q+\frac{h}{\sqrt{R}}\right) \end{pmatrix}$$

contains only the quantities J, q, which are not the same in both systems; and we may therefore represent this matrix by (J, q), and the corresponding matrix with h', b', c', J', q' by (J', q'). The two matrices are at once seen to be convertible (the assumed relations $h':b':c'=h:b:c$ correspond in fact to the conditions, $a'-d':b':c'=a-d:b:c$, of convertibility for the ordinary form), and the compound matrix is found to be

$$\left(\frac{\sin(q+q')}{\sin q \sin q'}JJ', q+q'\right).$$

And in like manner the several convertible matrices (J, q), (J', q'), (J'', q'') &c. give the compound matrix

$$\left(\frac{\sin(q+q'+q''..)}{\sin q \sin q' \sin q''..}JJ'J''.., q+q'+q''..\right).$$

FRANKLIN INSTITUTE LIBRARY.

48. The convertible matrices may be given in the first instance in the ordinary form, or we may take these matrices to be

$$\begin{pmatrix} a, & b \\ c, & d \end{pmatrix}, \begin{pmatrix} a', & b' \\ c', & d' \end{pmatrix}, \begin{pmatrix} a'', & b'' \\ c'', & d'' \end{pmatrix} \text{ \&c.}$$

where of course $d-a:b:c=d'-a':b':c'=d''-a'':b'':c''=$&c. Here writing $h=d-a$, and consequently $R=-(d-a)^2-4bc$, and assuming also $J=\frac{1}{2}\sqrt{R}$ and $\cot q=\frac{d+a}{\sqrt{R}}$, and in like manner for the accented letters, the several matrices are respectively

$$(\tfrac{1}{2}\sqrt{R}, q)\ (\tfrac{1}{2}\sqrt{R'}, q'), (\tfrac{1}{2}\sqrt{R''}, q''), \text{ \&c.},$$

and the compound matrix is

$$\left(\frac{\sin(q+q'+q''..)}{\sin q \sin q' \sin q''..}(\tfrac{1}{2}\sqrt{R})(\tfrac{1}{2}\sqrt{R'})(\tfrac{1}{2}\sqrt{R''})..,\ q+q'+q''+..\right).$$

49. When the several matrices are each of them equal to

$$\begin{pmatrix} a, & b \\ c, & d \end{pmatrix},$$

we have of course $q=q'=q''..$, $R=R'=R''..$, and we find

$$\begin{pmatrix} a, & b \\ c, & d \end{pmatrix}^n=\left(\frac{\sin nq}{\sin^n q}(\tfrac{1}{2}\sqrt{R})^n, nq\right);$$

or substituting for the right-hand side, the matrix represented by this notation, and putting for greater simplicity

$$\frac{\sin nq}{\sin^n q}(\tfrac{1}{2}\sqrt{R})^n=(\tfrac{1}{2}\sqrt{R})L, \text{ or } L=\frac{\sin nq}{\sin^n q}(\tfrac{1}{2}\sqrt{R})^{n-1},$$

we find

$$\begin{pmatrix} a, & b \\ c, & d \end{pmatrix}^n=\begin{pmatrix} \frac{1}{2}L\left(\sqrt{R}\cot nq-(d-a)\right), & Lb \\ Lc & ,\frac{1}{2}L\left(\sqrt{R}\cot nq+(d-a)\right) \end{pmatrix}$$

where it will be remembered that

$$R=-(d-a)^2-4bc \text{ and } \cot q=\frac{d+a}{\sqrt{R}},$$

the last of which equations may be replaced by

$$\cos q+\sqrt{-1}\sin q=\frac{d+a+\sqrt{-R}}{2\sqrt{ad-bc}}.$$

The formula in fact extends to negative or fractional values of the index n, and when n is a fraction, we must, as usual, in order to exhibit the formula in its proper generality, write $q+2m\pi$ instead of q. In the particular case $n=\frac{1}{2}$, it would be easy to show the identity of the value of the square root of the matrix with that before obtained by a different process.

50. The matrix will be to a factor *près*, periodic of the nth order if only $\sin nq=0$, that is, if $q=\frac{m\pi}{n}$ (m must be prime to n, for if it were not, the order of periodicity would be not n itself, but a submultiple of n); but $\cos q=\frac{d+a}{2\sqrt{ad-bc}}$, and the condition is therefore

$$(d+a)^2-4(ad-bc)\cos^2\frac{m\pi}{n}=0,$$

or as this may also be written,

$$d^2+a^2-2ad\cos\frac{2m\pi}{n}+4bc\cos^2\frac{m\pi}{n}=0,$$

a result which agrees with those before obtained for the particular values 2 and 3 of the index of periodicity.

51. I may remark that the last preceding investigations are intimately connected with the investigations of BABBAGE and others in relation to the function $\phi x=\frac{ax+b}{cx+d}$.

I conclude with some remarks upon rectangular matrices.

52. A matrix such as

$$\left(\begin{array}{c,c,c} a, & b, & c \\ a', & b', & c' \end{array}\right)$$

where the number of columns exceeds the number of lines, is said to be a broad matrix; a matrix such as

$$\left(\begin{array}{c,c} a, & b \\ a', & b' \\ a'', & b'' \end{array}\right)$$

where the number of lines exceeds the number of columns, is said to be a deep matrix.

53. The matrix zero subsists in the present theory, but not the matrix unity. Matrices may be added or subtracted when the number of the lines and the number of the columns of the one matrix are respectively equal to the number of the lines and the number of the columns of the other matrix, and under the like condition any number of matrices may be added together. Two matrices may be equal or opposite the one to the other. A matrix may be multiplied by a single quantity, giving rise to a matrix of the same form; two matrices so related are similar to each other.

54. The notion of composition applies to rectangular matrices, but it is necessary that the number of lines in the second or nearer component matrix should be equal to the number of columns in the first or further component matrix; the compound matrix will then have as many lines as the first or further component matrix, and as many columns as the second or nearer component matrix.

55. As examples of the composition of rectangular matrices, we have

$$\left(\begin{array}{c,c,c} a, & b, & c \\ d, & e, & f \end{array}\right)\left(\begin{array}{c,c,c,c} a', & b', & c', & d' \\ e', & f', & g', & h' \\ i', & j', & k', & l' \end{array}\right)=\left(\begin{array}{c,c,c,c} (a,b,c)(a',e',i'), & (a,b,c)(b',f',j') & (a,b,c)(c',g',k'), & (a,b,c)(d',h',l') \\ (d,e,f)(a',e',i'), & (d,e,f)(b',f',j') & (d,e,f)(c',g',k'), & (d,e,f)(d',h',l') \end{array}\right),$$

and

$$\left(\begin{array}{cc} a & d \\ b & e \\ c & f \end{array}\right\}\left\{\begin{array}{cc} a', & b', & c', & d' \\ e', & f', & g', & h' \end{array}\right) = \left(\begin{array}{cccc} (a, & d\}(a', & e'), & (a, & d\}(b', & f'), & (a, & d\}(c', & g'), & (a, & d\}(d', & h') \\ (b, & e\}(a', & e'), & (b, & e\}(b', & f'), & (b, & e\}(c', & g'), & (b, & e\}(d', & h') \\ (c, & f\}(a', & e'), & (c, & f\}(b', & f'), & (e, & f\}(c', & g'), & (c, & f\}(d', & h') \end{array}\right).$$

56. In the particular case where the lines and columns of the one component matrix are respectively equal in number to the columns and lines of the other component matrix, the compound matrix is square, thus we have

$$\left(\begin{array}{ccc} a, & b, & c \\ d, & e, & f \end{array}\right\}\left\{\begin{array}{cc} a', & d' \\ b', & e' \\ c', & f' \end{array}\right) = \left(\begin{array}{cc} (a, & b, & c\}(a', & b', & c'), & (a, & b, & c\}(d', & e', & f') \\ (d, & e, & f\}(a', & b', & c'), & (d, & e, & f\}(d', & e', & f') \end{array}\right)$$

and

$$\left(\begin{array}{cc} a', & d' \\ b', & e' \\ c', & f' \end{array}\right\}\left\{\begin{array}{ccc} a, & b, & c \\ d, & e, & f \end{array}\right) = \left(\begin{array}{cc} (a', & d'\}(a, & d), & (a', & d'\}(b, & e), & (a', & d'\}(c, & f) \\ (b', & e'\}(a, & d), & (b', & e'\}(b, & e), & (b', & e'\}(c, & f) \\ (c', & f'\}(a, & d), & (c', & f'\}(b, & e), & (c', & f'\}(c, & f) \end{array}\right)$$

The two matrices in the case last considered admit of composition in the two different orders of arrangement, but as the resulting square matrices are not of the same order, the notion of the convertibility of two matrices does not apply even to the case in question.

57. Since a rectangular matrix cannot be compounded with itself, the notions of the inverse or reciprocal matrix and of the powers of the matrix and the whole resulting theory of the functions of a matrix, do not apply to rectangular matrices.

58. The notion of transposition and the symbol tr. apply to rectangular matrices, the effect of a transposition being to convert a broad matrix into a deep one and reciprocally. It may be noticed that the symbol tr. may be used for the purpose of expressing the law of composition of square or rectangular matrices. Thus treating (a, b, c) as a rectangular matrix, or representing it by $\left(\begin{array}{ccc} a, & b, & c \end{array}\right)$, we have

$$\text{tr.}\left(\begin{array}{ccc} a', & b', & c' \end{array}\right) = \left(\begin{array}{c} a' \\ b' \\ c' \end{array}\right),$$

and thence

$$\left(\begin{array}{ccc} a, & b, & c \end{array}\right)\text{tr.}\left(\begin{array}{ccc} a', & b', & c' \end{array}\right) = \left(\begin{array}{ccc} a, & b, & c \end{array}\right\}\left(\begin{array}{c} a' \\ b' \\ c' \end{array}\right) = (a, b, c\}(a', b', c'),$$

so that the symbol

$$(a, b, c\}(a', b', c')$$

would upon principle be replaced by

$$\left(\begin{array}{ccc} a, & b, & c \end{array}\right)\text{tr.}\left(\begin{array}{ccc} a', & b', & c' \end{array}\right):$$

it is however more convenient to retain the symbol

$$(a, b, c \between a', b', c').$$

Hence introducing the symbol tr. only on the left-hand sides, we have

$$\begin{pmatrix} a, & b, & c \\ d, & e, & f \end{pmatrix} \text{tr.} \begin{pmatrix} a', & b', & c' \\ d', & e', & f' \end{pmatrix} = \begin{pmatrix} (a, & b, & c \between a', & b', & c'), & (a, & b, & c \between d', & e', & f') \\ (d, & e, & f \between a', & b', & c'), & (d, & e, & f \between d', & e', & f') \end{pmatrix},$$

or to take an example involving square matrices,

$$\begin{pmatrix} a, & b \\ d, & e \end{pmatrix} \text{tr.} \begin{pmatrix} a', & b' \\ d', & e' \end{pmatrix} = \begin{pmatrix} (a, & b \between a', & b'), & (a, & b \between d', & e') \\ (d, & e \between a', & b'), & (d, & e \between d', & e') \end{pmatrix},$$

so that in the composition of matrices (square or rectangular), when the second or nearer component matrix is expressed as a matrix preceded by the symbol tr., any *line* of the compound matrix is obtained by compounding the corresponding *line* of the first or further component matrix successively with the several *lines* of the matrix which preceded by tr. gives the second or nearer component matrix. It is clear that the terms 'symmetrical' and 'skew symmetrical' do not apply to rectangular matrices.

III. *A Memoir on the Automorphic Linear Transformation of a Bipartite Quadric Function.* By ARTHUR CAYLEY, *Esq.*, *F.R.S.*

Received December 10, 1857,—Read January 14, 1858.

THE question of the automorphic linear transformation of the function $x^2+y^2+z^2$, that is the transformation by linear substitutions, of this function into a function $x_,^2+y_,^2+z_,^2$ of the same form, is in effect solved by some formulæ of EULER's for the transformation of coordinates, and it was by these formulæ that I was led to the solution in the case of the sum of n squares, given in my paper "Sur quelques propriétés des déterminants gauches*." A solution grounded upon an *à-priori* investigation and for the case of any quadric function of n variables, was first obtained by M. HERMITE in the memoir "Remarques sur une Mémoire de M. CAYLEY relatif aux déterminants gauches†." This solution is in my Memoir "Sur la transformation d'une function quadratique en elle-même par des substitutions linéaires‡," presented under a somewhat different form involving the notation of matrices. I have since found that there is a like transformation of a bipartite quadric function, that is a lineo-linear function of two distinct sets, each of the same number of variables, and the development of the transformation is the subject of the present memoir.

1. For convenience, the number of variables is in the analytical formulæ taken to be 3, but it will be at once obvious that the formulæ apply to any number of variables whatever. Consider the bipartite quadric

$$\left(\begin{array}{ccc} a, & b, & c \\ a', & b', & c' \\ a'', & b'', & c'' \end{array}\right\}(x, y, z)(\mathrm{x}, \mathrm{y}, \mathrm{z})$$

which stands for

$$\begin{aligned} &(ax+by+cz)\mathrm{x} \\ &+(a'x+b'y+c'z)\mathrm{y} \\ &+(a''x+b''y+c''z)\mathrm{z}, \end{aligned}$$

and in which (x, y, z) are said to be the nearer variables, and $(\mathrm{x}, \mathrm{y}, \mathrm{z})$ the further variables of the bipartite.

* CRELLE, t. xxxii. pp. 119–123 (1846).

† Cambridge and Dublin Mathematical Journal, t. ix. pp. 63–67 (1854).

‡ CRELLE, t. l. pp. 288–299 (1855).

2. It is clear that we have

$$\left(\begin{array}{c} a\,,\ b\,,\ c \\ a',\ b',\ c' \\ a'',\ b'',\ c'' \end{array}\right)(x,\ y,\ z)(\mathrm{x},\ \mathrm{y},\ \mathrm{z})=\left(\begin{array}{c} a,\ a',\ a'' \\ b,\ b',\ b'' \\ c,\ c',\ c'' \end{array}\right)(\mathrm{x},\ \mathrm{y},\ \mathrm{z})(x,\ y,\ z)$$

and the new form on the right-hand side of the equation may also be written

$$(\mathrm{tr.}\left(\begin{array}{c} a\,,\ b\,,\ c \\ a',\ b',\ c' \\ a'',\ b'',\ c'' \end{array}\right)(\mathrm{x},\ \mathrm{y},\ \mathrm{z})(x,\ y,\ z),$$

that is, the two sets of variables may be interchanged provided that the matrix is transposed.

3. Each set of variables may be linearly transformed: suppose that the substitutions are

$$(x,\ y,\ z)=\left(\begin{array}{c} l\,,\ m\,,\ n \\ l',\ m',\ n' \\ l'',\ m'',\ n'' \end{array}\right)(x_{\prime},\ y_{\prime},\ z_{\prime})$$

and

$$(\mathrm{x},\ \mathrm{y},\ \mathrm{z})=\left(\begin{array}{c} \mathrm{l}\,,\ \mathrm{l}'\,,\ \mathrm{l}'' \\ \mathrm{m},\ \mathrm{m}',\ \mathrm{m}'' \\ \mathrm{n}\,,\ \mathrm{n}',\ \mathrm{n}'' \end{array}\right)(\mathrm{x}_{\prime},\ \mathrm{y}_{\prime},\ \mathrm{z}_{\prime})$$

Then first substituting for (x, y, z) their values in terms of $(x_{\prime}, y_{\prime}, z_{\prime})$, the bipartite becomes

$$\left(\left(\begin{array}{c} a\,,\ b\,,\ c \\ a',\ b',\ c' \\ a'',\ b'',\ c'' \end{array}\right)\left(\begin{array}{c} l\,,\ m\,,\ n \\ l',\ m',\ n' \\ l'',\ m'',\ n'' \end{array}\right)\right)(x_{\prime},\ y_{\prime},\ z_{\prime})(\mathrm{x},\ \mathrm{y},\ \mathrm{z})$$

Represent for a moment this expression by

$$\left(\begin{array}{c} \mathrm{A}\,,\ \mathrm{B}\,,\ \mathrm{C}\,, \\ \mathrm{A}',\ \mathrm{B}',\ \mathrm{C}', \\ \mathrm{A}'',\ \mathrm{B}'',\ \mathrm{C}'', \end{array}\right)(x_{\prime},\ y_{\prime},\ z_{\prime})(\mathrm{x},\ \mathrm{y},\ \mathrm{z}),$$

then substituting for $(\mathrm{x}, \mathrm{y}, \mathrm{z})$ their values in terms of $(\mathrm{x}_{\prime}, \mathrm{y}_{\prime}, \mathrm{z}_{\prime})$, it is easy to see that the expression becomes

$$\left(\left(\begin{array}{c} \mathrm{l}\,,\ \mathrm{m}\,,\ \mathrm{n} \\ \mathrm{l}',\ \mathrm{m}',\ \mathrm{n}' \\ \mathrm{l}'',\ \mathrm{m}'',\ \mathrm{n}'' \end{array}\right)\left(\begin{array}{c} \mathrm{A}\,,\ \mathrm{B}\,,\ \mathrm{C} \\ \mathrm{A}',\ \mathrm{B}',\ \mathrm{C}' \\ \mathrm{A}'',\ \mathrm{B}'',\ \mathrm{C}'' \end{array}\right)\right)(x_{\prime},\ y_{\prime},\ z_{\prime})(\mathrm{x}_{\prime},\ \mathrm{y}_{\prime},\ \mathrm{z}_{\prime}),$$

and re-establishing the value of the auxiliary matrix, we obtained, finally, as the result

of the substitutions,

$$\left(\begin{array}{c|c} a, b, c & \\ a', b', c' & \\ a'', b'', c'' & \end{array}\right)\!\!\left(x, y, z\right)\!\!\left(\mathrm{x}, \mathrm{y}, \mathrm{z}\right)=\left(\left(\begin{array}{c|c} \mathrm{l}, \mathrm{m}, \mathrm{n} & \\ \mathrm{l}', \mathrm{m}', \mathrm{n}' & \\ \mathrm{l}'', \mathrm{m}'', \mathrm{n}'' & \end{array}\right)\!\!\left(\begin{array}{c|c} a, b, c & \\ a', b', c' & \\ a'', b'', c'' & \end{array}\right)\!\!\left(\begin{array}{c|c} l, m, n & \\ l', m', n' & \\ l'', m'', n'' & \end{array}\right)\right)\!\!\left(x_{\prime}, y_{\prime}, z_{\prime}\right)\!\!\left(\mathrm{x}_{\prime}, \mathrm{y}_{\prime}, \mathrm{z}_{\prime}\right)$$

that is, the matrix of the transformed bipartite is obtained by compounding in order first or furthest the transposed matrix of substitution of the further variables, next the matrix of the bipartite, and last or nearest the matrix of substitution of the nearer variables.

4. Suppose now that it is required to find the automorphic linear transformation of the bipartite

$$\left(\begin{array}{c|c} a, b, c & \\ a', b', c' & \\ a'', b'', c'' & \end{array}\right)\!\!\left(x, y, z\right)\!\!\left(\mathrm{x}, \mathrm{y}, \mathrm{z}\right),$$

or as it will henceforward for shortness be written,

$$(\Omega)\!\!\left(x, y, z\right)\!\!\left(\mathrm{x}, \mathrm{y}, \mathrm{z}\right).$$

This may be effected by a method precisely similar to that employed by M. Hermite for an ordinary quadric. For this purpose write

$$x+x_{\prime}=2\xi\,,\quad y+y_{\prime}=2\eta\,,\quad z+z_{\prime}=2\zeta,$$
$$\mathrm{x}+\mathrm{x}_{\prime}=2\Xi,\quad \mathrm{y}+\mathrm{y}_{\prime}=2\mathrm{H},\quad \mathrm{z}+\mathrm{z}_{\prime}=2\mathrm{Z},$$

or as these equations may be represented,

$$(x+x_{\prime},\quad y+y_{\prime},\quad z+z_{\prime})=2(\xi\,,\eta\,,\zeta),$$
$$(\mathrm{x}+\mathrm{x}_{\prime},\quad \mathrm{y}+\mathrm{y}_{\prime},\quad \mathrm{z}+\mathrm{z}_{\prime})=2(\Xi, \mathrm{H}, \mathrm{Z}),$$

we ought to have

$$(\Omega)\!\!\left(2\xi-x, 2\eta-y, 2\zeta-z\right)\!\!\left(2\Xi-\mathrm{x}, 2\mathrm{H}-\mathrm{y}, 2\mathrm{Z}-\mathrm{z}\right)=(\Omega)\!\!\left(x, y, z\right)\!\!\left(\mathrm{x}, \mathrm{y}, \mathrm{z}\right).$$

5. The left-hand side is

$$4(\Omega)\!\!\left(\xi, \eta, \zeta\right)\!\!\left(\Xi, \mathrm{H}, \mathrm{Z}\right)-2(\Omega)\!\!\left(x, y, z\right)\!\!\left(\Xi, \mathrm{H}, \mathrm{Z}\right)-2(\Omega)\!\!\left(\xi, \eta, \zeta\right)\!\!\left(\mathrm{x}, \mathrm{y}, \mathrm{z}\right)+(\Omega)\!\!\left(x, y, z\right)\!\!\left(\mathrm{x}, \mathrm{y}, \mathrm{z}\right),$$

and the equation becomes

$$2(\Omega)\!\!\left(\xi, \eta, \zeta\right)\!\!\left(\Xi, \mathrm{H}, \mathrm{Z}\right)-(\Omega)\!\!\left(x, y, z\right)\!\!\left(\Xi, \mathrm{H}, \mathrm{Z}\right)-(\Omega)\!\!\left(\xi, \eta, \zeta\right)\!\!\left(\mathrm{x}, \mathrm{y}, \mathrm{z}\right)=0,$$

or as it may be written,

$$\left.\begin{array}{r}(\Omega)\!\!\left(\xi, \eta, \zeta\right)\!\!\left(\Xi, \mathrm{H}, \mathrm{Z}\right)-(\Omega)\!\!\left(x, y, z\right)\!\!\left(\Xi, \mathrm{H}, \mathrm{Z}\right)\\ +(\Omega)\!\!\left(\xi, \eta, \zeta\right)\!\!\left(\Xi, \mathrm{H}, \mathrm{Z}\right)-(\Omega)\!\!\left(\xi, \eta, \zeta\right)\!\!\left(\mathrm{x}, \mathrm{y}, \mathrm{z}\right)\end{array}\right\}=0;$$

or again,

$$\left.\begin{array}{r}(\Omega)\!\!\left(\xi-x, \eta-y, \zeta-z\right)\!\!\left(\Xi, \mathrm{H}, \mathrm{Z}\right)\\ +(\Omega)\!\!\left(\xi, \eta, \zeta\right)\!\!\left(\Xi-\mathrm{x}, \mathrm{H}-\mathrm{y}, \mathrm{Z}-\mathrm{z}\right)\end{array}\right\}=0,$$

or what is the same thing,

$$\left.\begin{array}{r}(\Omega)\!\!\left(\xi-x, \eta-y, \zeta-z\right)\!\!\left(\Xi, \mathrm{H}, \mathrm{Z}\right)\\ +(\mathrm{tr.}\Omega)\!\!\left(\Xi-\mathrm{x}, \mathrm{H}-\mathrm{y}, \mathrm{Z}-\mathrm{z}\right)\!\!\left(\xi, \eta, \zeta\right)\end{array}\right\}=0,$$

and it is easy to see that the equation will be satisfied by writing

$$(\ \Omega\between\xi-x, \eta-y, \zeta-z)=(\Upsilon\ \between\xi, \eta, \zeta),$$
$$(\mathrm{tr.}\Omega\between\Xi-\mathrm{x}, \mathrm{H}-\mathrm{y}, \mathrm{Z}-\mathrm{z})=-(\mathrm{tr.}\Upsilon\between\Xi, \mathrm{H}, \mathrm{Z}),$$

where Υ is any arbitrary matrix. In fact we have then

$$(\ \Omega\between\xi-x, \eta-y, \zeta-z\between\Xi, \mathrm{H}, \mathrm{Z})=(\ \Upsilon\between\xi, \eta, \zeta\between\Xi, \mathrm{H}, \mathrm{Z}),$$
$$(\mathrm{tr.}\Omega\between\Xi-\mathrm{x}, \mathrm{H}-\mathrm{y}, \mathrm{Z}-\mathrm{z}\between\xi, \eta, \zeta)=-(\mathrm{tr.}\Upsilon\between\Xi, \mathrm{H}, \mathrm{Z}\between\xi, \eta, \zeta)$$
$$=-(\ \Upsilon\between\xi, \eta, \zeta\between\Xi, \mathrm{H}, \mathrm{Z}),$$

and the sum of the two terms consequently vanishes.

6. The equation

$$(\Omega\between\xi-x, \eta-y, \zeta-z)=(\Upsilon\between\xi, \eta, \zeta)$$

gives

$$(\Omega-\Upsilon\between\xi, \eta, \zeta)=(\Omega\between x, y, z),$$

and we then have

$$(\Omega+\Upsilon\between\xi, \eta, \zeta)=(\Omega\between x_\prime, y_\prime, z_\prime).$$

In fact the two equations give

$$(2\Omega\between\xi, \eta, \zeta)=(\Omega\between x+x_\prime, y+y_\prime, z+z_\prime),$$

or what is the same thing,

$$2(\xi, \eta, \zeta)=(x+x_\prime, y+y_\prime, z+z_\prime),$$

which is the equation assumed as the definition of (ξ, η, ζ); and conversely, this equation, combined with either of the two equations, gives the other of them.

7. We have consequently

$$(x, y, z)=(\Omega^{-1}(\Omega-\Upsilon)\between\xi, \eta, \zeta),$$
$$(\xi, \eta, \zeta)=((\Omega+\Upsilon)^{-1}\Omega\between x_\prime, y_\prime, z_\prime),$$

and thence

$$(x, y, z)=(\Omega^{-1}(\Omega-\Upsilon)(\Omega+\Upsilon)^{-1}\Omega\between x_\prime, y_\prime, z_\prime).$$

8. But in like manner the equation

$$(\mathrm{tr.}\ \Omega\between\Xi-\mathrm{x}, \mathrm{H}-\mathrm{y}, \mathrm{Z}-\mathrm{z})=-(\mathrm{tr.}\ \Upsilon\between\Xi, \mathrm{H}, \mathrm{Z})$$

gives

$$(\mathrm{tr.}\ \overline{\Omega+\Upsilon}\between\Xi, \mathrm{H}, \mathrm{Z})=(\mathrm{tr.}\ \Omega\between\mathrm{x}, \mathrm{y}, \mathrm{z}),$$

and we then obtain

$$(\mathrm{tr.}\ \overline{\Omega-\Upsilon}\between\Xi, \mathrm{H}, \mathrm{Z})=(\mathrm{tr.}\ \Omega\between\mathrm{x}_\prime, \mathrm{y}_\prime, \mathrm{z}_\prime).$$

9. In fact these equations give

$$(\mathrm{tr.}\ 2\Omega\between\Xi, \mathrm{H}, \mathrm{Z})=(\mathrm{tr.}\ \Omega\between\mathrm{x}+\mathrm{x}_\prime, \mathrm{y}+\mathrm{y}_\prime, \mathrm{z}+\mathrm{z}_\prime),$$

or

$$2(\Xi, \mathrm{H}, \mathrm{Z})=(\mathrm{x}+\mathrm{x}_\prime, \mathrm{y}+\mathrm{y}_\prime, \mathrm{z}+\mathrm{z}_\prime);$$

and conversely, this equation, combined with either of the two equations, gives the other of them. We have then

$$(\mathrm{x}, \mathrm{y}, \mathrm{z})=((\mathrm{tr.}\ \Omega)^{-1}(\mathrm{tr.}\ \overline{\Omega+\Upsilon}\between\Xi, \mathrm{H}, \mathrm{Z}),$$
$$(\Xi, \mathrm{H}, \mathrm{Z})=((\mathrm{tr.}\ \overline{\Omega-\Upsilon})^{-1}\ \mathrm{tr.}\ \Omega\between\mathrm{x}_\prime, \mathrm{y}_\prime, \mathrm{z}_\prime),$$

and thence

$$(\mathrm{x},\ \mathrm{y},\ \mathrm{z})=((\mathrm{tr.}\,\Omega)^{-1}(\mathrm{tr.}\,\overline{\Omega+\Upsilon})(\mathrm{tr.}\,\overline{\Omega-\Upsilon})^{-1}\mathrm{tr.}\,\Omega\between(\mathrm{x}_{\prime},\ \mathrm{y}_{\prime},\ \mathrm{z}_{\prime}).$$

10. Hence, recapitulating, we have the following theorem for the automorphic linear transformation of the bipartite

$$(\Omega\between x,\ y,\ z\between(\mathrm{x},\ \mathrm{y},\ \mathrm{z}),$$

viz. Υ being an arbitrary matrix, if

$$(x,\ y,\ z)=(\Omega^{-1}(\Omega-\Upsilon)(\Omega+\Upsilon)^{-1}\Omega\between(x_{\prime},\ y_{\prime},\ z_{\prime}),$$

$$(\mathrm{x},\ \mathrm{y},\ \mathrm{z})=((\mathrm{tr.}\,\Omega)^{-1}(\mathrm{tr.}\,\overline{\Omega+\Upsilon})(\mathrm{tr.}\,\overline{\Omega-\Upsilon})^{-1}\mathrm{tr.}\,\Omega\between(\mathrm{x}_{\prime},\ \mathrm{y}_{\prime},\ \mathrm{z}_{\prime}),$$

then

$$(\Omega\between x,\ y,\ z\between(\mathrm{x},\ \mathrm{y},\ \mathrm{z})=(\Omega\between x_{\prime},\ y_{\prime},\ z_{\prime}\between(\mathrm{x}_{\prime},\ \mathrm{y},\ \mathrm{z}),$$

which is the theorem in question.

11. I have thought it worth while to preserve the foregoing investigation, but the most simple demonstration is the verification *à posteriori* by the actual substitution of the transformed values of $(x,\ y,\ z)$, $(\mathrm{x},\ \mathrm{y},\ \mathrm{z})$. To effect this, recollecting that in general $\mathrm{tr.}\,(\mathrm{A}^{-1})=(\mathrm{tr.}\,\mathrm{A})^{-1}$ and $\mathrm{tr.}\,\mathrm{ABCD}=\mathrm{tr.}\,\mathrm{D.}\ \mathrm{tr.}\,\mathrm{C.}\ \mathrm{tr.}\,\mathrm{B.}\ \mathrm{tr.}\,\mathrm{A}$, the transposed matrix of substitution for the further variables is

$$\Omega(\Omega-\Upsilon)^{-1}(\Omega+\Upsilon)\Omega^{-1};$$

and compounding this with the matrix Ω of the bipartite and the matrix

$$\Omega^{-1}(\Omega-\Upsilon)(\Omega+\Upsilon)^{-1}\Omega$$

of substitution for the nearer variables, the theorem will be verified if the result is equal to the matrix Ω of the bipartite, that is, we ought to have

$$\Omega(\Omega-\Upsilon)^{-1}(\Omega+\Upsilon)\Omega^{-1}\Omega\Omega^{-1}(\Omega-\Upsilon)(\Omega+\Upsilon)^{-1}\Omega=\Omega,$$

or what is the same thing,

$$\Omega(\Omega-\Upsilon)^{-1}(\Omega+\Upsilon)\Omega^{-1}(\Omega-\Upsilon)(\Omega+\Upsilon)^{-1}\Omega=\Omega;$$

this is successively reducible to

$$(\Omega+\Upsilon)\Omega^{-1}(\Omega-\Upsilon)\quad=(\Omega-\Upsilon)\Omega^{-1}(\Omega+\Upsilon)$$

$$\Omega^{-1}(\Omega+\Upsilon)\Omega^{-1}(\Omega-\Upsilon)=\Omega^{-1}(\Omega-\Upsilon)\Omega^{-1}(\Omega+\Upsilon)$$

$$(1+\Omega^{-1}\Upsilon)(1-\Omega^{-1}\Upsilon)\ =(1-\Omega^{-1}\Upsilon)(1+\Omega^{-1}\Upsilon),$$

which is a mere identity, and the theorem is thus shown to be true.

12. It is to be observed that in the general theorem the transformations or matrices of substitution for the two sets of variables respectively are not identical, but it may be required that this shall be so. Consider first the case where the matrix Ω is symmetrical, the necessary condition is that the matrix Υ shall be skew symmetrical; in fact we have then

$$\mathrm{tr.}\,\Omega=\Omega,\ \mathrm{tr.}\,\Upsilon=-\Upsilon,$$

and the transformations become

$$(x,\ y,\ z)=(\Omega^{-1}(\Omega-\Upsilon)(\Omega+\Upsilon)^{-1}\Omega\between(x_{\prime},\ y_{\prime},\ z_{\prime}),$$

$$(\mathrm{x},\ \mathrm{y},\ \mathrm{z})=(\Omega^{-1}(\Omega-\Upsilon)(\Omega+\Upsilon)^{-1}\Omega\between(\mathrm{x}_{\prime},\ \mathrm{y}_{\prime},\ \mathrm{z}_{\prime}),$$

which are identical. We may in this case suppose that the two sets of variables become equal, and we have then the theorem for the automorphic linear transformation of the ordinary quadric

$$(\Omega\between x, y, z)^2,$$

viz. Υ being a skew symmetrical matrix, if

$$(x, y, z)=(\Omega^{-1}(\Omega-\Upsilon)(\Omega+\Upsilon)^{-1}\Omega\between x_l, y_l, z_l),$$

then

$$(\Omega\between x, y, z)^2=(\Omega\between x_l, y_l, z_l)^2.$$

13. Next, if the matrix Ω be skew symmetrical, the condition is that the matrix Υ shall be symmetrical; we have in this case tr. $\Omega=-\Omega$, tr. $\Upsilon=\Upsilon$, and the four factors in the matrix of substitution for (x, y, z) are respectively $-\Omega^{-1}$, $-(\Omega-\Upsilon)$, $-(\Omega+\Upsilon)^{-1}$ and $-\Omega$, and such matrix of substitution becomes therefore, as before, identical with that for (x, y, z); we have therefore the following theorem for the automorphic linear transformation of a skew symmetrical bipartite

$$(\Omega\between x, y, z\between \mathrm{x}, \mathrm{y}, \mathrm{z}),$$

when the transformations for the two sets of variables are identical, viz. Υ being any symmetrical matrix, if

$$(x, y, z)=(\Omega^{-1}(\Omega-\Upsilon)(\Omega+\Upsilon)^{-1}\Omega\between x_l, y_l, z_l),$$
$$(\mathrm{x}, \mathrm{y}, \mathrm{z})=(\Omega^{-1}(\Omega-\Upsilon)(\Omega+\Upsilon)^{-1}\Omega\between \mathrm{x}_l, \mathrm{y}_l, \mathrm{z}_l),$$

then

$$(\Omega\between x, y, z\between \mathrm{x}, \mathrm{y}, \mathrm{z})=(\Omega\between x_l, y_l, z_l\between \mathrm{x}_l, \mathrm{y}_l, \mathrm{z}_l).$$

14. Lastly, in the general case where the matrix Ω is anything whatever, the condition is

$$\Omega^{-1}\Upsilon=-(\mathrm{tr.}\,\Omega)^{-1}\,\mathrm{tr.}\,\Upsilon$$

for assuming this equation, then first

$$\Omega^{-1}(\Omega-\Upsilon)=(\mathrm{tr.}\,\Omega)^{-1}(\mathrm{tr.}\,\overline{\Omega+\Upsilon}),$$

and in like manner

$$\Omega^{-1}(\Omega+\Upsilon)=(\mathrm{tr.}\,\Omega)^{-1}(\mathrm{tr.}\,\overline{\Omega-\Upsilon}).$$

But we have

$$1=(\mathrm{tr.}\,\Omega)^{-1}(\mathrm{tr.}\,\overline{\Omega-\Upsilon})(\mathrm{tr.}\,\overline{\Omega-\Upsilon})^{-1}\mathrm{tr.}\,\Omega,$$

and therefore, secondly,

$$(\Omega+\Upsilon)^{-1}\Omega=(\mathrm{tr.}\,\overline{\Omega-\Upsilon})^{-1}\mathrm{tr.}\,\Omega;$$

and thence

$$\Omega^{-1}(\Omega-\Upsilon)(\Omega+\Upsilon)^{-1}\Omega=(\mathrm{tr.}\,\Omega)^{-1}(\mathrm{tr.}\,\overline{\Omega+\Upsilon})(\mathrm{tr.}\,\overline{\Omega-\Upsilon})^{-1}\mathrm{tr.}\,\Omega,$$

or the two transformations are identical.

15. To further develope this result, let Ω^{-1} be expressed as the sum of a symmetrical matrix Ω_s and a skew symmetrical matrix Ω_l, and let Υ be expressed in like manner as the sum of a symmetrical matrix Υ_s and a skew symmetrical matrix Υ_l. We have then

$$\begin{aligned}
\Omega^{-1} &= Q_0+Q_1,\\
(\text{tr.}\,\Omega)^{-1}=\text{tr.}\,(\Omega^{-1}) &= Q_0-Q_1,\\
\Upsilon &= \Upsilon_0+\Upsilon_1,\\
\text{tr.}\,\Upsilon &= \Upsilon_0-\Upsilon_1,
\end{aligned}$$

and the condition, $\Omega^{-1}\Upsilon=-(\text{tr.}\,\Omega)^{-1}\,\text{tr.}\,\Upsilon$, becomes

$$(Q_0+Q_1)(\Upsilon_0+\Upsilon_1)=-(Q_0-Q_1)(\Upsilon_0-\Upsilon_1),$$

that is,

$$Q_0\Upsilon_0+Q_1\Upsilon_1=0,$$

and we have

$$\Upsilon_0=-Q_0^{-1}Q_1\Upsilon_1,$$

or as we may write it,

$$\Upsilon_0=-(\tfrac{1}{2}\{\Omega^{-1}+\text{tr.}\,\Omega^{-1}\})^{-1}(\tfrac{1}{2}\{\Omega^{-1}-\text{tr.}\,\Omega^{-1}\})\Upsilon_1,$$

and thence

$$\Upsilon=-(\tfrac{1}{2}\{\Omega^{-1}+\text{tr.}\,\Omega^{-1}\})^{-1}(\tfrac{1}{2}\{\Omega^{-1}-\text{tr.}\,\Omega^{-1}\})\Upsilon_1+\Upsilon_1,$$

where Υ_1 is an arbitrary skew symmetrical matrix.

16. This includes the before-mentioned special cases; first, if Ω is symmetrical, then we have simply $\Upsilon=\Upsilon_1$, an arbitrary skew symmetrical matrix, which is right. Next, if Ω is skew symmetrical, then $\Upsilon=-0^{-1}\Omega^{-1}\Upsilon_1+\Upsilon_1$, which can only be finite for $\Upsilon_1=0$, that is, we have $\Upsilon=-0^{-1}\Omega^{-1}0$, and (the first part of Υ being always symmetrical) this represents an arbitrary symmetrical matrix. The mode in which this happens will be best seen by an example. Suppose

$$\Omega^{-1}=\begin{pmatrix} A, & H+\nu \\ H-\nu, & B \end{pmatrix},\quad \text{tr.}\,\Omega^{-1}=\begin{pmatrix} A, & H-\nu \\ H+\nu, & B \end{pmatrix}$$

and write

$$\Upsilon_1=\begin{pmatrix} 0, & \theta \\ -\theta, & 0 \end{pmatrix}$$

then we have

$$\Upsilon=-\begin{pmatrix} A, & H \\ H, & B \end{pmatrix}^{-1}\begin{pmatrix} 0, & \nu \\ -\nu, & 0 \end{pmatrix}\begin{pmatrix} 0, & \theta \\ -\theta, & 0 \end{pmatrix}+\begin{pmatrix} 0, & \theta \\ -\theta, & 0 \end{pmatrix}$$

$$=-\frac{\nu\theta}{AB-H^2}\begin{pmatrix} -B, & H \\ H, & -A \end{pmatrix}+\begin{pmatrix} 0, & \theta \\ -\theta, & 0 \end{pmatrix}$$

$$=\begin{pmatrix} \dfrac{\nu B\theta}{AB-H^2}, & \dfrac{-\nu H\theta}{AB-H^2}+\theta \\ \dfrac{-\nu H\theta}{AB-H^2}-\theta, & \dfrac{\nu A\theta}{AB-H^2} \end{pmatrix}+\begin{pmatrix} 0, & \theta \\ -\theta, & 0 \end{pmatrix}$$

When Ω is skew symmetrical, A, B, H vanish; but since their ratios remain arbitrary, we may write $\varkappa A$, $\varkappa B$, $\varkappa H$ for A, B, H, and assume ultimately $\varkappa=0$. Writing $\varkappa\theta$ in the place of θ, and then putting $\varkappa=0$, the matrix becomes

FRAN INS LIBRAR

$$\begin{pmatrix} \frac{\nu B\theta}{AB-H^2}, & \frac{-\nu H\theta}{AB-H^2} \\ \frac{-\nu H\theta}{AB-H^2}, & \frac{\nu A\theta}{AB-H^2} \end{pmatrix}$$

which, inasmuch as $A:\theta$, $B:\theta$, and $C:\theta$ remain arbitrary, represents, as it should do, an arbitrary symmetrical matrix.

17. Hence, finally, we have the following Theorem for the automorphic linear transformation of the bipartite quadric,

$$(\Omega\between x, y, z\between \mathrm{x}, \mathrm{y}, \mathrm{z}),$$

when the two transformations are identical, viz. if Υ_1 be a skew symmetrical matrix, and if

$$\Upsilon = -(\tfrac{1}{2}\{\Omega^{-1}+\mathrm{tr}.\Omega^{-1}\})(\tfrac{1}{2}\{\Omega^{-1}-\mathrm{tr}.\Omega^{-1}\})\Upsilon_1+\Upsilon_1;$$

then if

$$(x, y, z)=(\Omega^{-1}(\Omega-\Upsilon)(\Omega+\Upsilon)^{-1}\Omega\between x_1, y_1, z_1),$$

$$(\mathrm{x}, \mathrm{y}, \mathrm{z})=(\Omega^{-1}(\Omega-\Upsilon)(\Upsilon+\Upsilon)^{-1}\Omega\between \mathrm{x}_1, \mathrm{y}_1, \mathrm{z}_1);$$

We have

$$(\Omega\between x, y, z\between \mathrm{x}, \mathrm{y}, \mathrm{z})=(\Omega\between x_1, y_1, z_1\between \mathrm{x}_1, \mathrm{y}_1, \mathrm{z}_1);$$

and in particular,

If Ω is a symmetrical matrix, then Υ is an arbitrary skew symmetrical matrix;

If Ω is a skew symmetrical matrix, then Υ is an arbitrary symmetrical matrix.

IV. *Supplementary Researches on the Partition of Numbers.*

By Arthur Cayley, *Esq.*, *F.R.S.*

Received March 19,—Read June 18, 1857.

The general formula given at the conclusion of my memoir, "Researches on the Partition of Numbers*," is somewhat different from the corresponding formula of Professor Sylvester†, and leads more directly to the actual expression for the number of partitions, in the form made use of in my memoir; to complete my former researches, I propose to explain the mode of obtaining from the formula the expression for the number of partitions.

The formula referred to is as follows, viz. if $\frac{\phi x}{fx}$ be a rational fraction, the denominator of which is made up of factors (the same or different) of the form $1-x^m$, and if a is a divisor of one or more of the indices m, and k is the number of indices of which it is a divisor, then

$$\left\{\frac{\phi x}{fx}\right\}_{[1-x^a]}=\cdots+\frac{1}{\Pi(s-1)}(x\partial_x)^{s-1}\mathrm{S}\frac{\chi\varrho}{\varrho-x}\cdots$$

$$=\cdots+\frac{1}{\Pi(s-1)}(x\partial_x)^{s-1}\frac{\theta x}{[1-x^a]}\cdots$$

where

$$\chi\varrho=\text{coeff. }\frac{1}{t}\text{ in }t^{s-1}\frac{\varrho\phi(\varrho e^{-t})}{f(\varrho e^{-t})},$$

in which formula $[1-x^a]$ denotes the irreducible factor of $1-x^a$, that is, the factor which equated to zero gives the prime roots, and ϱ is a root of the equation $[1-x^a]=0$; the summation of course extends to all the roots of the equation. The index s extends from $s=1$ to $s=k$; and we have then the portion of the fraction depending on the denominator $[1-x^a]$. In the partition of numbers, we have $\phi x=1$, and the formula becomes therefore

$$\left\{\frac{1}{fx}\right\}_{[1-x^a]}=\cdots+\frac{1}{\Pi(s-1)}(x\partial_x)^{s-1}\mathrm{S}\frac{\chi\varrho}{\varrho-x}\cdots$$

$$=\cdots+\frac{1}{\Pi(s-1)}(x\partial_x)^{s-1}\frac{\theta x}{[1-x^a]},$$

where

$$\chi\varrho=\text{coeff. }\frac{1}{t}\text{ in }t^{s-1}\frac{\varrho}{f(\varrho e^{-t})}.$$

* Philosophical Transactions, t. cxlvi. p. 127 (1856).

† Professor Sylvester's researches are published in the Quarterly Mathematical Journal, t. i. p. 141; there are some numerical errors in his value of P (1, 2, 3, 4, 5, 6) q.

We may write
$$fx=\Pi(1-x^m),$$
where m has a given series of values the same or different. The indices not divisible by a may be represented by n, the other indices by ap, we have then
$$fx=\Pi(1-x^n)\Pi(1-x^{ap}),$$
where the number of indices ap is equal to k. Hence
$$f(\varrho e^{-t})=\Pi(1-\varrho^n e^{-nt})\Pi(1-\varrho^{ap}e^{-apt});$$
or since ϱ is a root of $[1-x^a]=0$, and therefore $\varrho^a=1$, we have
$$f(\varrho e^{-t})=\Pi(1-\varrho^n e^{-nt})\Pi(1-e^{-apt});$$
and it may be remarked that if $n\equiv\nu$ (mod. a), where $\nu<a$, then instead of ϱ^n we may write ϱ^ν, a change which may be made at once, or at the end of the process of development.

We have consequently to find
$$\chi\varrho=\text{coeff. }\frac{1}{t}\text{ in }t^{a-1}\frac{\varrho}{\Pi(1-\varrho^n e^{-nt})\Pi(1-e^{-apt})}.$$
The development of a factor $\frac{1}{1-\varrho^n e^{-nt}}$ is at once deduced from that of $\frac{1}{1-ce^{-t}}$, and is a series of positive powers of t. The development of a factor $\frac{1}{1-e^{-apt}}$ is deduced from that of $\frac{1}{1-e^{-t}}$, and contains a term involving $\frac{1}{t}$. Hence we have
$$\frac{1}{\Pi(1-\varrho^n e^{-nt})\Pi(1-e^{-apt})}=A_{-k}\frac{1}{t^k}+A_{-(k-1)}\frac{1}{t^{k-1}}\ldots+A_{-1}\frac{1}{t}+A_0+\&c.,$$
and thence
$$\chi\varrho=\varrho A_{-k}.$$
The actual development, when k is small (for instance $k=1$ or $k=2$), is most readily obtained by developing each factor separately and taking the product. To do this we have
$$\frac{1}{1-ce^{-t}}=\frac{1}{1-c}-\frac{c}{(1-c)^2}t+\frac{c+c^2}{(1-c)^3}\tfrac{1}{2}t^2-\frac{c+4c^2+c^3}{(1-c)^4}\tfrac{1}{6}t^3+\&c.,$$
where by a general theorem for the expansion of any function of e^t, the coefficient of t^f is
$$=\frac{(-)^f}{\Pi f}\frac{1}{1-c(1+\Delta)}0^f$$
$$=\frac{(-)^f}{\Pi f}\left(\frac{1}{1-c}+\frac{c}{(1-c)^2}\Delta\ldots+\frac{c^f}{(1-c)^{f+1}}\right)0^f$$
(where as usual $\Delta 0^f=1^f-0^f$, $\Delta^2 0^f=2^f-2.1^f+0^f$, &c.) and
$$\frac{1}{1-e^{-t}}=\frac{1}{t}+\frac{1}{2}+\frac{1}{12}t-\frac{1}{720}t^3+\frac{1}{30240}t^5-\&c.,$$
where, except the constant term, the series contains odd powers only and the coefficient of t^{2f-1} is $\frac{(-)^{f+1}B_f}{\Pi 2f}$; B_1, B_2, B_3... denoting the series $\frac{1}{6}$, $\frac{1}{30}$, $\frac{1}{42}$... of BERNOULLI's numbers.

But when k is larger, it is convenient to obtain the development of the fraction from that of the logarithm, the logarithm of the fraction being equal to the sum of the logarithms of the simple factors, and these being found by means of the formulæ

$$\log\frac{1}{1-ce^{-t}}=\log\frac{1}{1-c}-\frac{c}{1-c}t+\frac{c}{(1-c)^2}\frac{t^2}{2}-\frac{c+c^2}{(1-c)^3}\frac{t^3}{6}+\frac{c+4c^2+c^3}{(1-c)^4}\frac{t^4}{24}+\&c.$$

$$\log\frac{1}{1-e^{-t}}=-\log t+\frac{1}{2}t-\frac{1}{24}t^3+\frac{1}{2880}t^4-\frac{1}{181440}t^5+\&c.$$

The fraction is thus expressed in the form

$$\frac{1}{\Pi(1-\varrho^a)\Pi(ap)}\frac{1}{t^k}e^{k_1t+k_3t^3+\cdots};$$

and by developing the exponential we obtain, as before, the series commencing with $A_{-k}\frac{1}{t^k}$.

Resuming now the formula

$$\chi\varrho=\varrho A_{-s},$$

which gives $\chi\varrho$ as a function of ϱ, we have

$$\frac{\theta x}{[1-x^a]}=S\frac{\chi\varrho}{\varrho-x};$$

but this equation gives

$$\chi\varrho=\theta\varrho\left(\frac{\varrho-x}{[1-x^a]}\right)_{x=\rho},$$

and we have

$$[1-x^a]=(x-\varrho)(x-\varrho^{a_2})\ldots(x-\varrho^{a_\alpha})$$

if $1, a_2, \ldots a_\alpha$ are the integers less than a and prime to it (α is of course the degree of $[1-x^a]$). Hence

$$\chi\varrho=\theta\varrho\frac{-1}{\varrho^{\alpha-1}\Pi(1-\varrho^{a_i-1})},$$

and therefore

$$\theta\varrho=-\varrho^{\alpha-1}\Pi(1-\varrho^{a_i-1})\chi\varrho;$$

or putting for $\chi\varrho$ its value

$$\theta\varrho=-\varrho^{\alpha}\Pi(1-\varrho^{a_i-1})A_{-s},$$

where α is the degree of $[1-x^a]$ and a_i denotes in succession the integers (exclusive of unity) less than a and prime to it. The function on the right-hand, by means of the equation $[1-\varrho^a]=0$, may be reduced to an integral function of ϱ of the degree $\alpha-1$, and then by simply changing ϱ into x we have the required function θx. The fraction $\frac{\theta x}{[1-x^a]}$ can then by multiplication of the terms by the proper factor be reduced to a fraction with the denominator $1-x^a$, and the coefficients of the numerator of this fraction are the coefficients of the corresponding prime circulator ( )pcr a_q.

Thus, let it be required to find the terms depending on the denominator $[1-x^3]$ in

$$\frac{1}{(1-x)(1-x^2)(1-x^3)(1-x^4)(1-x^5)(1-x^6)};$$

these are

$$S\frac{\chi_1\varrho}{\varrho-x},\quad x\partial_x S\frac{\chi_2\varrho}{\varrho-x},$$

where

$$\chi_1\varrho=\text{coeff. }\frac{1}{t}\text{ in }\frac{\varrho}{f(\varrho e^{-t})}$$

$$\chi_2\varrho=\text{coeff. }\frac{1}{t}\text{ in }t\frac{\varrho}{f(\varrho e^{-t})}$$

and

$$\frac{1}{f(\varrho e^{-t})}=\frac{1}{(1-\varrho e^{-t})(1-\varrho^3e^{-3t})(1-\varrho^4e^{-4t})(1-\varrho^5e^{-5t})(1-e^{-3t})(1-e^{-5t})}$$

$$=A_{-3}\frac{1}{t^3}+A_{-1}\frac{1}{t}+\text{ \&c.},$$

where it is easy to see that

$$A_{-3}=\frac{1}{18}\frac{1}{(1-\varrho)(1-\varrho^3)(1-\varrho^4)(1-\varrho^5)}$$

$$A_{-1}=\frac{1}{(1-\varrho)(1-\varrho^3)(1-\varrho^4)(1-\varrho^5)}\left\{\frac{1}{4}-\frac{1}{18}\left(\frac{\varrho}{1-\varrho}+\frac{2\varrho^2}{1-\varrho^3}+\frac{4\varrho^4}{1-\varrho^4}+\frac{4\varrho^5}{1-\varrho^5}\right)\right\},$$

and we have

$$\theta_3\varrho=-\varrho^3(1-\varrho)A_{-3}$$

$$\theta_1\varrho=-\varrho^3(1-\varrho)A_{-1}.$$

But $[1-\varrho^5]=1+\varrho+\varrho^2=0$. Hence $\varrho^3=1$, and therefore

$$(1-\varrho)(1-\varrho^3)(1-\varrho^4)(1-\varrho^5)=(1-\varrho)^3(1-\varrho^2)^2=9.$$

Hence

$$\theta_3\varrho=-\frac{1}{162}\varrho^3(1-\varrho)=\frac{1}{162}(1-\varrho^2)=\frac{1}{162}(2+\varrho),$$

whence

$$\theta_3x=\frac{1}{162}(2+x),$$

and the partial fraction is

$$\frac{1}{162}\frac{2+x}{1+x+x^2},$$

which is

$$=\frac{1}{162}\frac{2-x-x^2}{1-x^3},$$

and gives rise to the prime circulator $\frac{1}{162}(2,-1,-1)$ per 3_q.

The reduction of $\theta_1\varrho$ is somewhat less simple; we have

$$\theta_1\varrho=-\frac{1}{9}\varrho^3(1-\varrho)\left\{\frac{1}{4}-\frac{1}{18}\left(\frac{\varrho}{1-\varrho}+\frac{2\varrho^2}{1-\varrho^2}+\frac{4\varrho}{1-\varrho}+\frac{5\varrho^2}{1-\varrho^3}\right)\right\}$$

$$=-\frac{1}{9}\varrho^3(1-\varrho)\left\{\frac{1}{4}-\frac{5}{18}\frac{\varrho}{1-\varrho}-\frac{7}{18}\frac{\varrho^2}{1-\varrho^3}\right\}$$

$$=\frac{1}{9}(1-\varrho^2)\left\{\frac{1}{4}-\frac{5}{54}\varrho(1-\varrho^2)-\frac{7}{54}\varrho^2(1-\varrho)\right\}$$

$$= \frac{1}{972}(1-\varrho^2)(51-10\varrho-14\varrho^2)$$

$$= \frac{1}{972}(61+4\varrho-65\varrho^2);$$

whence, finally,

$$\theta_1\varrho=\frac{1}{324}(42+23\varrho),\quad \theta_1 x=\frac{1}{324}(42+23x);$$

and the partial fraction is

$$\frac{1}{324}x\partial_x\frac{42+23x}{1+x+x^2},$$

which is

$$=\frac{1}{324}x\partial_x\frac{42-19x-23x^2}{1-x^3},$$

and gives rise to the prime circulator $\frac{1}{324}q(42, -19, -23)$ per 3_q.

The part depending on the denominator $1-x$ is

$$\frac{A_{-1}}{1-x}+\frac{1}{1}x\partial_x\frac{A_{-2}}{1-x}+\frac{1}{1.2}(x\partial_x)^2\frac{A_{-3}}{1-x}\cdots+\frac{1}{1.2.3.4.5}(x\partial_x)^5\frac{A_{-6}}{1-x},$$

where

$$\frac{1}{(1-e^{-t})(1-e^{-2t})(1-e^{-3t})(1-e^{-4t})(1-e^{-5t})(1-e^{-6t})}$$

$$=A_{-6}\frac{1}{t^6}+A_{-5}\frac{1}{t^5}\cdots+A_{-1}\frac{1}{t}+\text{ \&c.}$$

We have here

$$\log\frac{1}{1-e^{-t}}=-\log t+\frac{1}{2}t-\frac{1}{24}t^2+\frac{1}{2880}t^4-\text{ \&c.},$$

and thence the fraction is

$$\frac{1}{720\,t^6}\;e^{\frac{21}{2}t-\frac{91}{24}t^2+\frac{455}{576}t^4-\text{ \&c.}}$$

which is equal to

$$\frac{1}{720\,t^6}\Big(1+\frac{21}{2}t+\frac{441}{8}t^2+\frac{3087}{16}t^3+\frac{64827}{128}t^4+\frac{1361367}{1280}t^5+\cdots$$

$$\times\Big(1-\frac{91}{24}t^2+\frac{8281}{1152}t^4+\cdots\Big)$$

$$\times\Big(1+\frac{455}{576}t^4+\cdots\Big)$$

$$=\frac{1}{720}\frac{1}{t^6}+\frac{7}{480}\frac{1}{t^5}+\frac{77}{1080}\frac{1}{t^4}+\frac{245}{1152}\frac{1}{t^3}+\frac{43981}{103680}\frac{1}{t^2}+\frac{199577}{345600}\frac{1}{t}+\cdots$$

and consequently the partial fractions are

$$\frac{1}{86400}(x\partial_x)^5\frac{1}{1-x}+\frac{7}{11520}(x\partial_x)^4\frac{1}{1-x}+\frac{77}{6480}(x\partial_x)^3\frac{1}{1-x}+\frac{245}{2304}(x\partial_x)^2\frac{1}{1-x}$$

$$+\frac{43981}{103680}(x\partial_x)\frac{1}{1-x}+\frac{199577}{345600}\frac{1}{1-x},$$

from which the non-circulating part is at once obtained.

The complete expression for the number of partitions is $P(1, 2, 3, 4, 5, 6)q =$

$$\frac{1}{1036800}(12q^5+630q^4+1230q^3+110250q^2+439810q+598731)$$

$$+\ \frac{1}{4608}\ (6q^2+126q+581)(1, -1)\,\text{per}\,2_q$$

$$+\ \frac{1}{162}q\ \ldots\ldots\ldots\ (2, -1, -1)\,\text{per}\,3_q$$

$$+\ \frac{1}{324}\ \ldots\ldots\ (42, -19, -23)\,\text{per}\,3_q$$

$$+\ \frac{1}{32}\ \ldots\ldots\ (1, 1, -1, -1)\,\text{per}\,4_q$$

$$+\ \frac{1}{25}\ \ldots\ldots\ (2, 1, 0, -1, -2)\,\text{per}\,5_q$$

$$+\ \frac{1}{36}\ \ldots\ (2, 1, -1, -2, -1, 1)\,\text{per}\,6_q.$$

V. *An Account of some recent Researches near Cairo, undertaken with the view of throwing light upon the Geological History of the Alluvial Land of Egypt.—Instituted by* LEONARD HORNER, *Esq., Vice-President of the Royal Society, Fellow of the Royal Society of Edinburgh, and Vice-President of the Geological Society.*

PART II.

Received January 25,—Read February 11, 1858.

CONTENTS:—

	Page
Introduction,	
Nature of the Alluvial Soils	55
The recent Researches in the Memphis district	55
Inequalities in the surface of the ground	56
The excavations, shafts and borings at the Colossal Statue	57
Section of the first shaft and deepest boring at the Statue	58
Section of the second shaft and boring at the Statue	60
Pits sunk in the vicinity of the Statue	61
Pits across the valley in the parallel of Memphis	63
Pits across the valley in the parallel of Heliopolis	63
Review of the chief facts made known by the excavations, &c.	66
Circumstances which modify the deposition of the sediment in different parts of the valley	68
The underground filtration water	70
The rate of secular increase of the alluvial land	71
How far a local secular rate of increase of the alluvial land may, with probability, be estimated from these recent researches	73
Evidence which these researches would seem to afford of a very early existence of Man in Egypt	75
Appendix.	
Note A. Biographical sketch of HEKEKYAN BEY	78
Note B. Microscopic organisms in the Nile sediment	79
Note C. GIRARD's estimate of the secular increase of the land	80
Note D. Excavations by the French Engineers in 1799	84
Note E. BUNSEN on the early existence of Man in Egypt	86

AT the conclusion of the first part of this memoir*, I stated that, besides the operations at Heliopolis therein described, researches on a more extensive scale had subsequently been undertaken in the district of ancient Memphis and in the valley on the western

* Philosophical Transactions, 1855, Part I. p. 105. It may be useful for the reader to refer to the Introduction in Part I., where I describe the geological object of these researches, and the means by which I hoped that it might be accomplished.

side of the Nile in the parallel of Heliopolis. These researches I now proceed to describe.

In accordance with the opinion I entertained, when I undertook the inquiry, that excavations should be made in the vicinity of some very ancient monument, the age of which is known, I chose the site of the long extinct city of Memphis, now covered with the date groves of the modern village of Metrahenny, twenty miles above the parallel of Heliopolis, and about thirty miles above the apex of the Delta. All testimony appears to concur as to its very remote antiquity; in assigning its foundation to MENES, the first king of the first dynasty which reigned over Egypt, and who, according to LEPSIUS, the latest and very able expounder of Egyptian chronology, began his reign 3892 years before the Christian era.

HERODOTUS relates*, that MENES turned the course of the Nile eastward, by an embankment 100 stadia higher up the river, to dam out the inundations which then annually covered the land on which he proposed to erect his seat of government. Sir G. WILKINSON says†, that though we may still trace the spot where the diversion of the river was made, owing to the great bend it makes about fourteen miles above the site of Memphis, the lofty mounds raised there are no longer visible. This ancient city was thus built on land which, from its vicinity to the Nile, must have been annually overflowed, doubtless for many previous ages, and which, consequently, must have been covered with the sediment deposited by the annual inundations. It presented, therefore, a peculiarly fit situation for prosecuting this inquiry, by sinking pits to the greatest practicable depth beneath the level of the existing foundations of buildings or other monuments. As at Heliopolis the Obelisk is all that remains above ground of that city, so at Memphis there is one solitary monument of its former greatness, which has, in recent times, been uncovered, a fallen colossal statue of the great king RAMESSES II., MIANUN, the SESOSTRIS of the Greeks, which stood in front of one of its temples.

Supported by the powerful influence of our then Consul-General in Egypt, the Honourable CHARLES AUGUSTUS MURRAY, with the late Viceroy ABBAS PACHA, and encouraged by the intelligent zeal and energy shown in the researches at Heliopolis by my very able coadjutor, the Engineer HEKEKYAN BEY‡, my wish was accomplished. The Pacha placed at the disposal of the Bey all the requisite means for carrying on the operations in the most effective manner; and directed different departments of his government to cooperate with him. There were appointed to assist him OMAR EFFENDI, Adjutant of Artillery, two subaltern officers of the corps of Engineers of roads and bridges, a civil engineer to have special charge of the excavations and borings, and other officers to superintend the labourers. HEKEKYAN BEY had also the advantage of being assisted for some time by a German gentleman resident in Cairo, Herr ERBEN, whose scientific acquirements rendered his services of great value. The whole expenses of the researches, carried on during three seasons, of some original surveys, and the preparation of several

* Book ii. s. 99. † Ancient Egyptians, First Series, i. 89. ‡ Note A. Appendix, pp. 78, 79.

maps on a large scale, and many drawings, amounting altogether to a very considerable sum, have been, with great liberality, defrayed by the Egyptian Government.

Nature of the Alluvial Soils.

In the first part of this memoir I have entered fully into the nature of the solid matter held in suspension in the inundation water, and deposited on the land, from the samples then in my possession. I have found no essential difference between them and the samples I have since received from the later excavations and borings. There is very little variety throughout the whole valley from Memphis to the sea; an argillaceous earth or loam of different shades of colour, black, grey and brown, more or less mixed with fine sand, constitutes the chief part, often associated with quartzose sand of different degrees of coarseness, and of various shades of colour. This coarser sand is for the most part blown into the valley by violent winds from the deserts on both sides.

THE RECENT RESEARCHES IN THE MEMPHIS DISTRICT.

I intimated to HEKEKYAN BEY my wish that the first object of his attention should be, to sink a shaft close to the colossal statue at Metrahenny. This statue, which had fallen or been thrown down from its pedestal, is said to have been discovered by Signor CAVIGLIA, about thirty years ago. He had found some indications of buried sculpture between the modern villages of Metrahenny and Bedreshin, and on making an excavation around it to a depth of about 5 feet, he uncovered a statue in its whole length. HERODOTUS says* that SESOSTRIS erected two statues, each 30 cubits high, before the temple of Vulcan in Memphis, representing himself and his queen, and four statues of his sons, each 20 cubits high. The existing statue has been proved to be that of RAMESSES II., the SESOSTRIS of the Greeks†. Dr. LEPSIUS, in a letter with which he has favoured me, says,—"If we may assume that the Memphis statue represents RAMESSES while a young man, of which the absence of the beard would not be, of itself, a decided proof, we should then be justified in assigning it to the beginning of the fourteenth century before Christ. According to my estimate, RAMESSES MIANUN reigned from about 1394 to 1328 B.C."

I requested that, in making the excavation in this place, the following particulars should be attended to:—

To ascertain the height of the surface of the ground at the edge of CAVIGLIA's excavation above the low water of the Nile;

To search for the pedestal on which the statue had stood;

To measure the depth of soil from the surface of the ground down to the upper surface of the pedestal, if found;

To sink a vertical shaft close to one side of the pedestal;

* Book ii. 110.

† See a description of this statue by J. BONOMI, Esq., in the Transactions of the Royal Society of Literature, Second Series, vol. ii. p. 297.

To mark the depth from the surface of the ground to the lowest part of the pedestal;

To ascertain carefully the nature of the ground on which the pedestal rests;

To continue the sinking of the shaft, so long as the soil passed through should consist of alluvial deposit;

If no pedestal were found, that the shaft should be made close to the statue, and that a specimen of each variety of soil passed through should be carefully preserved.

By the middle of April 1852, the engineers had begun their preparations for the work, and on the 10th of May the researches commenced. Several shafts were sunk, which I shall notice hereafter, besides that at the colossal statue, for the operations were continued without interruption to the 3rd of October, and then, in spite of every effort to close the breaches in the embankments around the district in which the works were carried on, the Nile inundated all the pits, and compelled the party to take refuge on the neighbouring mounds.

Inequalities in the surface of the ground.

The surface of the ground for some distance around the colossal statue being uneven, it became necessary, in order to ascertain the variable depth of water during an inundation at the mouths of the pits in various parts of the area, now intended to be sunk, that the level of the highest rise of the water over that ground at a given time should be determined. Accordingly the Salibe level * of the flood of 1851 on the Libyan dyke of the river to the east of the village of Bedreshin was accurately ascertained, and was found to be $\frac{11}{24}$ths of a cubit (9·922 inches) above the twenty-fourth cubit mark on the Nilometer on the island of Rhoda near Cairo†. The line of the twenty-fourth cubit covers the entire surface of the valley, leaving above it artificial elevations, such as dykes, mounds of rubbish, and buildings. The inequalities of the ground are such that, in any section under the said twenty-fourth cubit level, the surface varies from where it coincides with that level to nearly twenty feet in the deepest part; so that while in one part of the district there might be a depth of nearly twenty feet of turbid water, in another it might be less than an inch; a circumstance of great importance to bear in mind in this inquiry. M. Talabot, in the report of the operations of the French Brigade in 1846–47, states that, in the latter year, the inundation rose to the twenty-fourth cubit mark of the Rhoda Nilometer, and that that mark is 71 feet 5½ inches above the mean level of the Mediterranean‡. The Nile having risen in 1851 ten inches above the twenty-fourth cubit mark, the distance by the river from the Nilometer to the parallel of Bedreshin being 13 miles, and the ascent of this part of the river being estimated at about 5½ inches in a mile, the level of the inundation water of 1851 over the site of the colossal statue, was thus 78 feet 3 inches above the mean level of the Mediterranean.

* The Salibe is the stationary level occupied by the inundation water at the autumnal equinox.

† Estimating the cubit at 55 centimetres, and 1 centimetre at 0·39371 of an inch, 24 cubits are nearly 43 feet 3½ inches.

‡ Mémoire de la Société d'Études de l'Isthme de Suez.

It will be observed on examining the sections of the pits hereafter described, that the further progress of sinking the shafts was stopped by water of filtration, and at very different depths from the surface of the ground; but in the most important of them the penetration of the soil was continued by boring. The remarkable circumstance of the very different depths at which the filtration water was reached, and that within a very limited area, will be best considered after the soils passed through in each pit have been described.

The Excavation, Shafts, and Borings at the Colossal Statue.

The excavation originally made by CAVIGLIA was enlarged by HEKEKYAN BEY, and, when completed, it measured 110 feet by 85. At a depth of 5 feet 8 inches from the surface of the ground, they came upon the upper surface of a platform on which the colossus had stood, composed of two courses of cyclopean masonry, a considerable portion of which still remains. The upper blocks are 31¼, the lower 35½ inches thick, and they lie perfectly horizontal. The lower course of blocks was found to rest upon a bed of sand 38 inches in thickness, which, from the section of the adjacent ground, appears to have been brought to the spot in order to form a more firm foundation for the platform. It is a grey quartzose sand, identical with that found at a depth of 16½ feet on the left bank of the Rosetta branch, at the apex of the Delta*. This foundation sand rests on Nile sediment.

The surface of the ground, at the margin of the excavation, was ascertained to be 3 feet 6½ inches under the inundation level of 1851, and thus, according to the measurements of M. TALABOT, 74 feet 8½ inches above the mean level of the Mediterranean.

When this excavation was commenced in August 1852, no part of the platform was visible; and after it had been continued down to the inferior surface of the lower course of masonry, all around the statue, it was deepened on the eastern side, and at a distance of 25 feet from the platform, a shaft was sunk to the depth of 16 feet 4¾ inches from the surface of the ground. At that depth, filtration water put a stop to further digging, and, on this first occasion, artificial means were not resorted to to draw it off. But borings were made in three places, in one to the depth of 7 feet, in another to the depth of 8 feet, and in a third to the depth of 23 feet 8 inches; that is, to a depth of 40 feet from the surface of the ground. In the latter case, the boring instrument was drawn up fourteen times, each time bringing up a core of soil, specimens of which were sent to me. Throughout the excavation and sinking of the shaft and the borings, there was no indication of a laminated structure in the soils, no trace of quietly deposited successive layers.

* Specimen I. Memoir, Part I. page 128.

Section of the first Shaft and deepest boring at the Statue of RAMESSES II.

Layer*.	Thickness of layer†.	Depth of the bottom of the layer from the surface of the ground.	Nature of the soils.
	inches.	inches.	
I.	7·875	.....	The surface layer at the superior ridge of the excavation, a brown sandy argillaceous earth, with a mixture of white sand, and small fragments of limestone and burnt brick. It closely resembles the standard specimen E, described in Part I. of this Memoir, page 127.
II.	23·625	31·500	Undistinguishable from I., except in being of a lighter colour.
III.	15·750	47·250	Scarcely distinguishable from I., except in being more indurated, like dried clay, and containing fragments of pottery.
IV.	31·500	78·750	Similar in all respects to III.
V.	35·375	114·125	Scarcely distinguishable from II. and III.
VI.	27·520	141·645	Almost identical with V., with fragments of limestone and brick.
VII.	15·730	157·375	Very similar to III. and VI., with fragments of burnt brick.
VIII.	39·375	196·750	Nearly identical with VII.
			16 feet, 4¾ inches. Filtration water, 4 August, 1852.
Boring layers.			
IX.	8·000	204·75	Light brown sandy argillaceous earth, with fragments of burnt brick.
X.	48·000	252·75	Dark brown argillaceous earth, with fragments of burnt brick and particles of pottery.
XI.	48·000	300·75	Similar to X., with fragments of limestone.
XII.	24·000	324·75	Similar to X., with fragments of burnt brick and pottery.
XIII.	12·000	336·75	Similar to IX., with fragments of burnt brick, pottery and limestone.
XIV.	12·000	348·75	A mixture of IX. and transparent quartzose sand.
XV.	12·000	360·75	Similar to XIV., but the earth of a lighter colour.
XVI.	24·000	384·75	Shining black sand, composed of rounded and crystalline grains of magnetic iron, and a few round grains of transparent quartz.
XVII.	12·000	396·75	Same as preceding, with a mixture of argillaceous earth.
XVIII.	12·000	408·75	Same as XVI.
XIX.	12·000	470·75	Same as XVII.
XX.	12·000	432·75	Same as XVII., with darker-coloured argillaceous earth.
XXI.	24·000	456·75	Same as XX., *but with fragments of burnt brick and pottery.*
XXII.	24·000	480·75	Same as XVI.
			40 feet from the surface of the ground.

It will thus be seen that, from about 2 feet 8 inches from the surface, indeed almost from the present surface of the ground, to the depth of 30 feet, there is very little difference in the nature of the soils. All the specimens sent to me consist of a sandy argillaceous earth or loam, of various shades of colour, from dark to light brown, differing somewhat in texture, some friable, some having more the character of clay, and some hardened into concretions.

Throughout this excavation and shaft, various objects of art and some bones of domestic animals were met with; the former of these may, at first sight, appear foreign to a geological treatise, but it must be remembered that the object of this inquiry has been to endeavour to trace back the history of the formation of the alluvial land from the present time, and therefore they have a bearing upon the question of the gradual

* By the term "layer" is to be understood merely certain distinctions adopted by HEKEKYAN BEY, founded, in the case of the argillaceous earths, chiefly on differences of colour, and partly on admixtures of sand.

† The measurements in English inches, in this and other sections, are those given by HEKEKYAN BEY; the minute decimals arising from his conversions of French metres into our measures.

accumulation of the sediment upon the area of Memphis. They have also a bearing upon an opinion I venture hereafter to express, that the evidence collected during these researches afford a strong presumption of the existence of man in Egypt, in a certain degree of civilization, long prior to all historical records. I have therefore made the following selection of these objects, as instances, showing the depths from the surface at which they were found:—

Fragment of a jar of coarse unglazed pottery	6 feet
Lower half of a small human figure in baked clay	6 feet
Cover of a jar of limestone	7 feet
Back part of the skull of a dog or large jackal	7 feet
Left metacarpal of an ass	7 feet
Small vase of coarse unglazed pottery	8 feet
Right metacarpal of a dromedary	9 feet
Valve of *Iridina rubens**	10 feet
Saucer of coarse pottery	10 feet
Hinder half of a small lion in baked clay	10 feet
Fragment of a jar with a stamped ornament	11 feet
Small fragment of coloured mosaic	12 feet
Valve of *Iridina rubens*	12 feet
Valve of *Spondylus gaderopus*†	12 feet
Blade of a copper knife‡	13 feet
Small vase of white pottery	14 feet
Small pot of brown unglazed pottery	15 feet

The boring instrument could not bring up large objects, but it will have been seen by the preceding section, that, at the depth of 38 feet, the sand contained small fragments of burnt brick and pottery.

In the summer of 1854 another pit was sunk at the colossal statue, midway towards

* CAILLAUD found *Iridina rubens* in considerable abundance in the Nile, and SOWERBY describes a species under the name of *Iridina nilotica* obtained from Sennaar by CAILLAUD.

† On showing this marine shell to the late Professor FORBES, he remarked that it had probably been carried thus far inland by a large bird.

‡ This blade has been analysed in the Metallurgical Laboratory in Jermyn Street, under the direction of Dr. PERCY, by Mr. CHARLES TOOKEY, and yielded the following results:—

Copper	97·12
Arsenic	2·29
Iron	0·43
Tin, with trace of gold	0·24
	100·08

Phosphorus was sought for, but no trace was found.

The arsenic may have existed in the copper ore; but the Ancient Egyptians may have known the art of hardening copper by adding a small proportion of arsenic.

the western side of the platform. In digging the former pit, when they reached the filtration water, no artificial means were resorted to to draw it off, in order to carry the shaft deeper, the further examination of the soils being made by borings; but in this new pit, shadoofs (buckets with levers) were employed, and the shaft was continued to a depth of 24 feet, by which means the nature of the soil was better shown at that greater depth than was possible by the borings.

The summit ridge of the excavation was the same as in the former pit, that is 3 feet 6½ inches below the inundation level of 1853, which was ascertained to have been the same as that of 1851. Although, as might be expected, there is a considerable resemblance between this pit and that already described, there still is a sufficient difference to induce me to give a detailed description of it, the more especially as it proved to be the most important of all the pits that were sunk.

Section of the second Shaft and Boring at the Statue of RAMESSES II.

Layer.	Thickness of layer.	Depth of the bottom of the layer from surface of the ground.	Nature of the soils.
	inches.	inches.	
I.	77·4334	.....	Light brown, sandy, argillaceous earth, with an admixture of transparent quartzose sand.
II.	30·4334	107·4334	Similar to I., with fragments of red brick.
III.	60·4334	167·4334	Similar to I., with fragments of limestone, brick and pottery.
IV.	125·1158	292·5492	The same as III.
			24 feet 4½ inches. Filtration water.
Boring layer.			
V.	36·1158	328·5492	Light brown argillaceous earth, with fragments of pottery.
VI.	84·1158	412·5492	Same as II., but without fragments of brick.
VII.	36·1158	448·5492	Dark brown argillaceous earth, with fragments of pottery.
VIII.	24·1158	472·5492	Blackish, compact, fine-grained argillaceous earth, with a few fragments of pottery.
IX.	24·1158	496·5492	Fine greenish-grey sand, mixed with argillaceous earth.
			41 feet 4½ inches.

Throughout this excavation also, objects of art and bones of domestic animals were met with, of which the following is a selection:—

Lower molar tooth of a small variety of Ox, } between 13 and 20 feet
Molar tooth, and end of the humerus of a Hog, } from the surface.
Neck of a vessel in coarse unglazed pottery at 21 feet.
Fragment of a small glass vessel, at the bottom of the shaft.
Cube of coarse sandstone, smoothed, as if used for polishing, ditto.
And from the lowest part of the boring, the tool brought up a fragment, about an inch square, of unglazed red pottery.

If the finer part of the surface layer be compared with the argillaceous sediment brought up by the boring instrument from the deepest part, they appear identical, with the exception of a slight difference in colour, and in a somewhat greater proportion of sand in the latter. Mr. BRAZIER, who analysed the standard specimens of Nile

sediment, as described in Part I. of this Memoir (page 125), undertook at my request analyses of the surface layer (A) and of the lowest part of the boring (B), which yielded the following results:—

		A.	B.
Soluble in hydrochloric acid.	Moisture ..... per cent.	3·24	3·36
	Organic matter	1·72	1·60
	Carbonate of lime	10·40	1·92
	Sesquioxide of iron	5·20	7·68
	Sesquioxide of alumina	2·81	2·46
	Magnesia	0·08	traces
	Sulphuric acid	0·16	0·02
	Phosphoric acid	traces	none
	Chlorine	traces	none
	Potassa	0·57	none
	Soda	0·85	none
Insoluble in hydrochloric acid.	Silica	64·55	74·96
	Sesquioxide of iron	6·45	5·83
	Sesquioxide of alumina	3·85	2·53
		99·88	100·36

Per-centage composition after deducting moisture.	A.	B.
Silica	66·80	77·28
Sesquioxide of iron	17·05	13·93
Sesquioxide of alumina	6·89	5·14
Carbonate of lime	10·76	1·98
Magnesia	0·08	traces
Potassa	0·59	none
Soda	0·88	none
Sulphuric acid	0·17	0·02
Phosphoric acid	traces	none
Chlorine	traces	none
Organic matter	1·78	1·65
	100·00	100·00

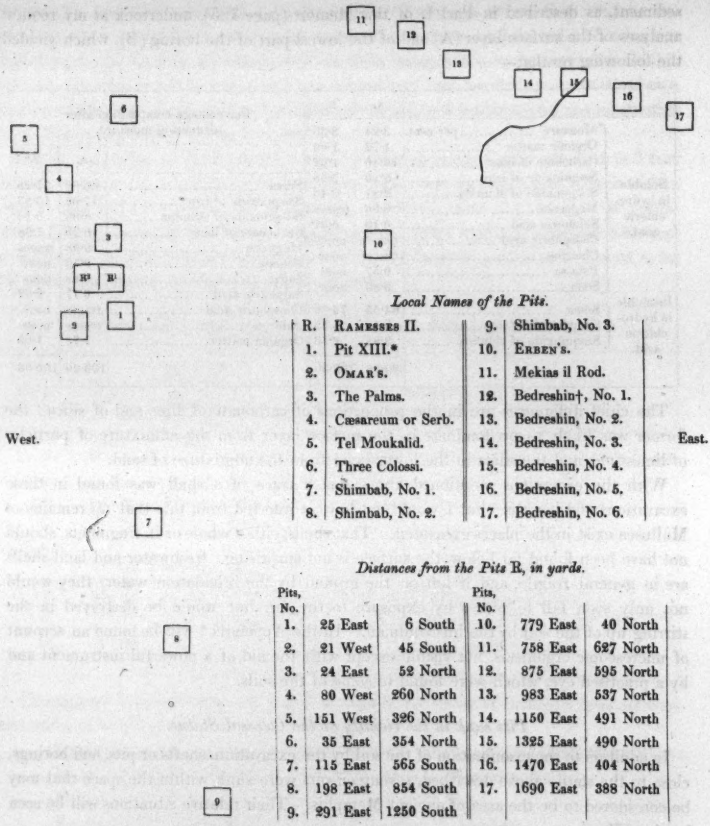
The chief differences are in the proportions of carbonate of lime and of silica: the former was likely to predominate in the surface layer from the admixture of particles of limestone, and the silica in the lower layer from the admixture of sand.

With the exceptions mentioned above, not a trace of a shell was found in these excavations and borings; but I would not have it inferred from this that no remains of Mollusca exist in the places excavated. That shells, either whole or in fragments, should not have been found far below the surface is not surprising: freshwater and land shells are in general fragile, and if left on the ground by the inundation water, they would not only soon fall to pieces by exposure to the air, but would be destroyed in the stirring up of the soil by the husbandman. In the Appendix* will be found an account of microscopic organisms, not visible except with the aid of a powerful instrument and by a practised eye, which were found in some of the soils.

Pits sunk in the vicinity of the Colossal Statue.

In addition to the examination of the soil by the excavation, shafts or pits, and borings, close to the statue above described, seventeen pits were sunk within the space that may be considered to be the area of ancient Memphis. Their relative situations will be seen by the following ground plan.

* Note B. Appendix, p. 79.



Local Names of the Pits.

R.	Ramesses II.	9.	Shimbab, No. 3.
1.	Pit XIII.*	10.	Erben's.
2.	Omar's.	11.	Mekias il Rod.
3.	The Palms.	12.	Bedreshin†, No. 1.
4.	Cæsareum or Serb.	13.	Bedreshin, No. 2.
5.	Tel Moukalid.	14.	Bedreshin, No. 3.
6.	Three Colossi.	15.	Bedreshin, No. 4.
7.	Shimbab, No. 1.	16.	Bedreshin, No. 5.
8.	Shimbab, No. 2.	17.	Bedreshin, No. 6.

Distances from the Pits R, *in yards.*

Pits, No.			Pits, No.		
1.	25 East	6 South	10.	779 East	40 North
2.	21 West	45 South	11.	758 East	627 North
3.	24 East	52 North	12.	875 East	595 North
4.	80 West	260 North	13.	983 East	537 North
5.	151 West	326 North	14.	1150 East	491 North
6.	35 East	354 North	15.	1325 East	490 North
7.	115 East	565 South	16.	1470 East	404 North
8.	198 East	854 South	17.	1690 East	388 North
9.	291 East	1250 South			

The sections of these pits will be seen in Plate II. The alluvial soil being divisible into two principal kinds, in the one of which argillaceous earth enters largely into the composition, while the other consists mainly, or altogether, of quartzose sand,

* Of the line of pits across the valley in the mound district of Memphis, described hereafter.

† Nos. 1 to 5 of the Bedreshin Pits were in the Summer Road, north of the cross embankment leading from Metrahenny to Bedreshin. No. 6 is west of the Bedreshin burial-grounds.

I have considered it sufficient in the illustrations of all the sections of the soils, given in this second part of my memoir, to distinguish these two main kinds by two shadings, the varieties of them by letters, and the accidental mixtures of fragments of limestone, brick and pottery by subordinate marks. I have prepared a list of the varieties of the soils, which precedes the explanations of the Plates of the Sections. To have given the Sections according to a true scale was obviously impossible within a moderate space, but I have shown, in the explanation accompanying each Plate, the distances, in yards, that intervene. By this method the variety of the soils that occur in the same plane will be more readily seen than by mere verbal descriptions.

In the Pit No. 2, there were met with, at a depth of 13 feet from the surface, a fragment of Assouan granite, sculptured, and an architectural carved ornament of limestone.

In No. 3, at a depth of 12½ feet, a female foot, carved in white limestone, and an ornamental vase of red pottery.

In No. 4, at a depth of 7 feet 2 inches, they came upon the surface of a course of large blocks of a red sandstone, resting upon pure sand, succeeded by a layer of sediment; at 9 feet 2 inches, a second course of large blocks of the same sandstone; and at 11 feet 8 inches, a third course of the same kind.

In No. 6, at depths of 8½ feet and 15 feet, several small statuettes in stone and bronze; at 26 feet, a fragment of wrought limestone; at 27½ feet, several bones of a hog; at 33½ feet, a tablet of calcareous sandstone, with portions of an inscription in hieroglyphics; and at 35 feet, fragments of pottery.

In the lowest part of No. 17, between 11 and 12 feet, the right humerus of an adult man; but this pit, it will be observed, was sunk on the west of the Bedreshin burial-grounds.

Pits across the Valley in the Parallel of Memphis.

Twenty-seven pits were opened in ground below the inundation level of 1851, in a line across the valley from the foot of the Libyan Hills on the west to the skirt of the Arabian Hills on the east of the Nile, nearly in the parallel of the colossal statue of Ramesses II., and embraced within an area extending about five miles from west to east, and one mile from north to south. Each pit was 5 feet square, and the excavation was continued until stopped by the filtration water. Sections of these pits are given in Plate III., accompanied by the necessary explanations.

Pits across the Valley in the Parallel of Heliopolis.

Extensive as the researches had already been, I was desirous of having further trials, made lower down the river, in the parallel of Heliopolis; and the consent of the Pacha having been obtained, through the kind and zealous intervention of Mr. Murray, and afterwards of his successor, Mr. Bruce, Hekekyan Bey, with unabated energy, undertook to conduct the further operations in the year 1854, partly by excavations, but chiefly by borings.

The first sinking in this line was in ground below the inundation level of 1853, which was very nearly the same as that of 1851, at a distance of fifty yards from the eastern slope of the Libyan Hills, and nearly eight miles from the left bank of the Nile. In this distance twenty-six trials were made. Passing over to the right bank, twenty-five trials were made in a space about eight miles westward. Thus fifty-one penetrations of the soil were made at intervals in a line across the valley of about sixteen miles, and sections of them are given in Plates IV. and V., with accompanying explanations. In each instance the boring terminated when the filtration water was reached. The operations were carried on in the month of July, except in four instances.

I would draw particular attention to the sections 24, 25 and 26, in Plate IV., and to section No. 1, in Plate V., on account of the great depths to which the borings were there continued.

The instrument employed was an iron graduated rod, having a deep threaded screw to work into the soil. The screw was conical, and the samples of soil were brought up from the several depths given without turning it; and in separating the sample, great care was taken to keep it clear of any soil adhering to the exterior of the screw, and the instrument was washed each time that it was drawn up, before the next descent.

The Boring No. 24 was made at the distance of fifteen yards from the left bank of the Nile, near the village of Sigiul, about ten miles below Cairo, the surface of the ground being 3 feet 10 inches below the inundation level of 1853. The operation was carried on from the 13th to the 17th of November 1854, and was continued to the depth of 50 feet. The soil consisted of 35 feet of argillaceous earth (Nile sediment), of various shades of brown, and 15 feet of bluish- and greenish-brown quartzose sand. The tool brought up particles of "rubbish"* from depths of 26, 28 and 32 feet.

The Boring No. 25 was in the same locality, at a short distance from No. 24, on the north side of the village, and was also continued to the depth of 50 feet, the surface of the ground being 3 feet above the surface at No. 24. The soil consisted of the same Nile sediment, to the depth of 32 feet, and of 18 feet of quartzose sands. Particles of "rubbish" were brought up from a depth of 32 feet, and the sand at 46 feet contained particles of limestone.

The Boring No. 26 was at the south-western extremity of the same village, 1330 yards above the intersection of the parallel of Heliopolis with the great Libyan dyke of the Nile, the surface of the ground being 4 feet above the surface at No. 24. It was made on the 21st of September, 1st and 5th of October 1854, and was continued to the depth of 50 feet. The soil penetrated consisted exclusively of Nile sediment, with some varieties of colour. From the last five feet, the tool brought up particles of "rubbish."

The Boring No. 1 in Plate V., was on the right bank of the river, at the north-western extremity of the village of Bessousse, nearly opposite to the village of Sigiul, and 722

* Hekekyan Bey, in using the term "rubbish," means particles and very frequently morsels of baked clay, usually red, and of limestone.

yards above the intersection of the parallel of Heliopolis with the great Arabian dyke of the Nile, the surface of the ground being 2 feet 5 inches below the inundation level of 1853. The boring was made from the 14th to the 17th of October, and from the 2nd to the 11th of November 1854, was carried down to the depth of 59 feet 10 inches, and yielded the following remarkable results:—

ft.	in.	
20	0	of ordinary Nile sediment.
8	4	of grey quartzose sand.
5	0	of Nile sediment.
2	0	of sand.
1	0	of Nile sediment.
11	0	of sands.
1	0	of Nile sediment.
11	6	of sands.
59	10	

Out of thirty-seven times that the boring tool was brought up, in twenty-one instances the soil contained particles of "rubbish," even at the lowest depths. Of the sixteen instances in which the "rubbish" was not found, the soil consisted of sand.

This boring had reached to within 7 feet 4½ inches of the mean level of the Mediterranean:—

	ft.	in.	ft.	in.
Level of the inundation water at Bedreshin, above the mean level of the Mediterranean			78	3
Deduct:—1. Fall from Bedreshin to the island of Rhoda . . .	5	6		
Fall from Rhoda to the parallel of Heliopolis, 10 miles, at the rate of 3¾ inches in a mile (Memoir, Part I. p. 114)	3	1½		
Surface of ground at the mouth of the boring below the inundation level	2	5		
			11	0½
Surface of the ground at the boring			67	2½
Depth of the boring			59	10
			7	4½

In this boring, the samples of soil down to the end of the 53rd foot from the surface of the ground, were extracted by turning the screw in the soil exactly a foot deep each time. The remainder of the depth was jumped through, and the samples brought up were estimated from the contents of the bottom tube in the screw.

Review of the chief facts made known by the Excavations, Shafts and Borings.

On examining the results of the ninety-five probings of the alluvial land which I have described in this second part of my memoir, we find,—

1st. That the alluvium is of two principal kinds; first, and chiefly, an argillaceous earth or loam, more or less mixed with fine sand, of various shades of colour, being the true Nile mud or sediment; and secondly, pure quartzose sand, derived in a great measure from the desert, being swept by violent winds through the gullies in the hills on either side, but chiefly from the Libyan range.

2ndly. That the Nile sediment found at the lowest depth reached is very similar in composition to that deposited by the inundation water of the present day.

3rdly. That in no instance did the boring instrument strike upon the solid rock, that which may be presumed to form the basin between the Libyan and Arabian Hills that contains the alluvium accumulated through unknown ages, from the time when this depression in the earth's surface was formed, and the waters of the Nile first flowed through it.

4thly. That, except minute organisms discoverable only by a powerful microscope, few organic remains were met with, and that those found were recent land and river shells, and bones of domestic animals.

5thly. That there has not been found a trace of an extinct organic body.

6thly. That at the same levels great varieties in the alluvium have been found in adjoining pits, even when the distances between them are very moderate. This will be at once seen by referring to the Sections.

7thly. That there is an absence of all lamination in the sediment. When I first undertook these researches, I expected that sediment, slowly deposited on the land from nearly tranquil water, would present, in sections, a laminated structure; more especially as an able observer, the late Captain NEWBOLD, has told us that he had met with such an arrangement of the alluvial soil*. It was therefore with no small surprise that I learned, when I received the account of the excavations at Heliopolis, that no such laminæ had been found; and in none of the excavations or borings since made has such a structure been met with in a single instance. There can be no doubt that a layer of sediment must be deposited upon the land, but so soon as the waters have subsided, the sun, the wind, and cultivation combine to break it up. From the earliest times when the Nile valley was inhabited by man, the alluvial land, fertilized by the sediment from the annual inundation, must have been cultivated in the returning seasons. The next following flood softens the hardened mud of the preceding year, and it is considered that this softening of the soil is one of the most fertilizing effects of the inundation. The very primitive and simple system of cultivation of the present day is most probably the same which had been followed for unknown ages, for it is said that in Egypt nothing changes. As the subsiding inundation level continues to expose to air and light

* Quarterly Journal of the Geological Society, vol. iv. 1848, pp. 343 and 344.

the surface on which the sediment has been deposited, in insulated patches of the uneven ground, the fellah, wading in mud, begins to throw seed upon them, in contour lines, his light boat bringing to him his seed corn. As the retreating waters expose more land, so soon as it is sufficiently drained, another zone of ground is sown, and so on until the lowest parts have received the seed, which must be cast before the surface begins to crack; and after it has been cast, it is beaten down into the mud with a flat piece of wood at the end of a pole. During the dry season, when vegetation withers, and the underground water has subsided, the ground cracks into numerous and deep fissures, forming the usual polygonal fissures we see in dry mud or clay, affording receptacles for the flying sand. For three or four months in every year the surface of the valley, stript of vegetation, in the state of a dry powder, is swept by violent winds, raising storms of dust. By these combined causes, therefore, every trace of the deposited layer must be effaced*. Instances of lamination and alternations of clay and sand, such as those mentioned by Captain NEWBOLD, are not unfrequently met with in the banks of the river, and at the entrances of canals; but they are local occurrences caused by eddies and currents. I have in my possession specimens of such laminated sediment from the right bank of the river near Helwan, a few miles above Cairo.

8thly. That there are occasional accumulations of soil, the materials of which are only remotely derived from the inundation water and the storms of desert sand. In the neighbourhood of old buildings, and on the sites of former buildings, where these have been constructed of crude bricks, the soil, to a considerable depth, may have been derived from the disintegration of these bricks. The soil, thus derived, would have nearly the same aspect as the natural deposit of Nile mud. In the Heliopolis excavation B (Memoir, Part I. p. 132), crude bricks were seen to have been the origin of the soil there by visible rectangular lines chequering the sides of the pit. This last appearance, however, must be a rare occurrence, for the action of the inundation water softens the bricks and causes them to melt, as it were, into a homogeneous mass.

9thly. That, in nearly every part of the ground penetrated, artificial substances have

* I have stated in Part I., p. 108, that, "with an inclination so slight as that of the land over which the inundation spreads, the solid insoluble matter must in great part remain where it is deposited." I did not then take into account the violent winds which swept over the parched land, and transport the soil in vast clouds of dust. Neither did I take into account the great absorption of the constituents of the soil by the grain crops which succeed the inundation. In JOHNSTON'S 'Elements of Agricultural Chemistry,' p. 71, we find the following statement:—"1000 lbs. of the ash of the straw of wheat, barley, oats, rye, and Indian corn have been found to contain respectively,—

	Wheat.	Barley.	Oats.	Rye.	Indian Corn.
Silica	654 lbs.	676 lbs.	484 lbs.	645 lbs.	270 lbs.
Lime	67	85	81	90	83
Magnesia	39	50	38	24	66
Oxide of iron	13	10	18	14	8
	773	821	621	773	427"

been found, such as fragments and particles of burnt brick and pottery, and in the area of Heliopolis and Memphis, fragments of statues and other sculptured stones.

Circumstances which modify the deposition of the sediment in different parts of the valley.

When the Nile first enters Egypt at Assouan, it is loaded with its greatest amount of solid matter, and with that which is coarsest and heaviest. In its progress, the heavier particles must be first deposited, and the solid matter thus becomes finer and finer as the river flows downwards, until at length it is in the state of an impalpable powder, which discolours the water, and is perceptible in the sea at a great distance from the land. As a proof of the more rapid deposition of the heavier particles, even so low down as Cairo, I may mention, that at the ebb of the river, after the inundation of 1853, it was found that the deposit on the Mastaba, or landing-place, of the Rhoda Nilometer, that is at the ninth cubit mark on the column, was 6 inches in thickness; on the fourth step above it, about $2\frac{1}{4}$ inches, and on the sixteenth step not more than $1\frac{1}{4}$, each step being rather more than 9 inches deep.

The deposition of the sediment must further be hastened in the upper parts of the river by two causes, the small amount of the fall and the evaporation under a burning sun. The course of the stream between Assouan and Cairo, according to the observations of RUSSEGGER, is 555 statute miles*, and Assouan being 300 feet above Cairo†, the mean fall of the river is thus 6·486 inches according to RUSSEGGER, 6·175 according to HEKEKYAN BEY, in a mile. The inundation of 1851 rose to the height of 78 feet at the parallel of Memphis, and to $63\frac{1}{2}$ feet at the apex of the Delta, difference $14\frac{1}{2}$ feet, and the distance between the two points being thirty miles, it gives a fall of 5·8 inches in a mile. From Assouan to Cairo, the river has nowhere a sufficient fall to be used as water power‡. The evaporation by the great heat in those latitudes from the broad surface of the river must be very great. M. GIRARD states§, that on plunging a thermometer into the sand that covers the surface of the desert, it rose to 56° of REAUMUR, or 158° of FAHRENHEIT; and Sir G. WILKINSON says‖ that "so rapidly does the ardent sun of Egypt, even in the months of November and December, dry the mud, when once deprived of its covering of water, that no fevers are generated, and no illness visits those villages which have been entirely surrounded by the inundation." The evaporating water, thus parting with its solid contents, must greatly accelerate the deposition in the higher parts of the river's course. There is also a constant source of irregularity in the amount of deposition at different parts of the valley from this cause, that the Nile frequently undermines its banks, and a vast quantity of the sediment of former years falls

* Reisen, Band ii. Theil i. 271, 120 German geographical miles, one mile=4⅘ and 25 yards, English. HEKEKYAN BEY considers RUSSEGGER's estimate to be under the truth, and that following the chief line of current of the Nile (say its line at low water), the total distance from Assouan to the point of Rhoda Island must be 583 miles.

† Id. 282 Paris feet.

‡ Id.

§ Mémoires de l'Institut, 1817, p. 286.

‖ Ancient Egyptians, 2nd series, i. 37.

into the stream; and, moreover, in those parts which are opposite to gullies in the hills bounding each side, much sand, blown from the desert, mingles with the muddy water.

The spreading of the waters over the lands must have been controlled by embankments from a very remote historic period, for otherwise the inhabitants of the valley would have been exposed to great dangers from the floods. For how long a period, the river, when it rose above the natural limits of its channel, overflowed the adjoining country without any artificial check, how much of the alluvial land had been formed before the system of embankments was adopted, it is impossible to ascertain; but it is evident that the rate at which the soil accumulated would be different from what it became when the water was no longer allowed to flow in its natural course. The longitudinal embankments extend at present to the narrow pass in the river at Gebel Silsilis, about forty-two miles below Assouan. From that point, downwards, the longitudinal dyke, called the King's Road, extends all the way along the left bank of the stream. The extent of the deposit on the right bank is variable, covering considerable areas in some localities, where the slope of the desert skirt is gentle. The river, therefore, from Silsilis to Cairo, about 542 miles, is nowhere allowed to overflow its banks, that is, to have a free unimpeded access to the valley. The alluvial land on both sides above the apex of the Delta, and throughout the Delta, is intersected by canals, and each canal has its longitudinal dykes, over which the current of muddy water, flowing through it, is not allowed to pass, but is made to flow through certain apertures in the dykes at the proper time, and at the proper places, and thus, to use the expression of HEKEKYAN BEY, "the water is let out upon the land by rule and measure," regulated by the Rhoda Nilometer.

The higher level from which the inundation water is taken enables it to flow far into the interior, and sluices at the mouths of the canals prevent it from being excessive. These great canals feed smaller ones, which again are subdivided, so as to spread over the land a network of irrigation. About the middle of August, when the Nile has risen to about two-thirds of the height between its standard lowest ebb and its standard Salibe level, the water enters the Magrour or Joseph's Canal, about 326 miles above Cairo*. It is then charged with sediment, and continues to flow along it with an increasing volume as the inundation water rises, until that attains its maximum, when it runs in a contrary direction. By various artificial means the water in the Magrour is forced to rise at different places, so as to spread over the adjacent lands. In this operation overflowing eddies are created, which cause unequal rates in the deposit of the sediment.

* "The Magrour (or water-course) is the second and upper bed of the Nile in its natural state. It generally keeps close to the western limits of the cultivable area of the valley. Its average latitudinal distance from the river is about 6½ miles; its greatest deviation about 13 miles; its closest approach, a little below Siout, about 1¼. It has been modified by works of art, particularly below Benisouef, where it gets the name of Bahr Jousseph or Joseph's Canal. Numerous cross canals make a connexion between the river and the Magrour. They claim for their origin certain natural water passages, as well from the river into the Magrour, as from the Magrour into the river. They are employed to drain the artificial inundation water from the grounds into the river, during the proper season, and to serve as canals of irrigation after the subsidence of the flood."—Letter of HEKEKYAN BEY, 8th January, 1858.

and these are also caused by irregularities in the surface of the ground. These eddies are often very wide, and according to their strength and velocity scoop out the ground, leaving sediment around the areas thus scooped out. Villages, dykes, plantations, and even solitary trees, together with the sinuosities of the valley, alter the direction, the extent, and the velocities of these inundation eddies, and consequently the quantities and areas of the deposits of sediment. Sometimes also the muddy water of the Nile is added to by torrents from the hills, which come down charged with clay and sand from the deserts. Hence some patches of land are of a dark brown argillaceous nature, others more or less yellow, and more or less sandy, in proportion to the matter suspended in the torrents, and according as their flow has been retarded. After the retiring of the flood, a series of lakes are found at different levels, produced by the eddies, and they are often filled up by the sand blowing over them being retained by the water. The removal of a plantation, the forming of a new one in another direction, a new dyke, a new hamlet, will all cause disturbances in the direction of the eddies, and consequent alterations in the nature and amount of the sediment deposited, causing also patches of land adjoining each other to fluctuate greatly in value to the cultivator.

The lands nearest the river which are irrigated by water, let in upon them direct from it, receive a greater amount of sediment, for the river water during the inundation has more suspended in it than that in the canals, especially those at a distance, and the river water must necessarily soon deposit the coarser and heavier matter. Thus the strips of land along the dykes that skirt the river, and the dykes of the great canals being irrigated by water holding the maximum of suspended matter, are generally higher than the rest of the valley; and, from the same cause, the strip of land between the river's ordinary channel and its embankment is higher than that on the other side of the embankment.

From the above description of the various circumstances which affect the distribution of the Nile sediment over the land, it is obvious that the depth of the annual deposit by the inundation must be very different in different parts of the valley, *and consequently the same lapse of time may be represented by different depths of the soil.*

The underground filtration Water.

On examining the sections of the pits, it will be seen that filtration water was reached at very different levels, at the same period of the year, even in the case of those separated only by a short distance. Thus, in Plate II.—

	feet.
In Pit R[1], on 4th August 1852, it was reached at	19
In Pit No. 2, 45 yards south, on the same day	16
In Pit No. 3, 52 yards north, on the same day	17
In Pit No. 4, 260 yards north, on 29th June	30

In Plate III.—

In Pit No. 1, on 22nd August 1852, at	10·9
In Pit No. 2, 66 yards east of No. 1, on the same day	15·9

	feet.
In Pit No. 3, 475 yards east of No. 2, on 24th July 1852 . . .	13·0
In Pit No. 4, 246 yards east of No. 3, on 24th July 1852 . . .	19·3
In Pit No. 5, 517 yards east of No. 4, on 24th July 1852 . . .	13·3
In Pit No. 6, 333 yards east of No. 5, on 25th July 1852 . . .	14·9
In Pit No. 7, 150 yards east of No. 6, on 25th July 1852 . . .	17·3
In Pit No. 8, 354 yards east of No. 7, on 25th July 1852 . . .	16·6

On all occasions when the soil was penetrated, the progress of excavation was stopped, except in the second shaft at the colossal statue, by filtration water, after which the further examination could only be made by borings. This impediment I did not anticipate; and I fear that it must ever be found a great obstacle to any satisfactory ascertaining of the nature and depth of the entire amount of Nile sediment in any section of the valley. It is a well-authenticated fact, that no wells can be sunk with any certainty as to the depth at which water will be found, in any part of the valley, even within a comparatively limited space. This irregularity in the levels must be caused to a great extent by differences in the degrees of permeability and power of retention in the soils; but it will be seen, on examining the sections in the instances quoted above, that the soils of the different pits are very much of the same kind, and it is not very likely that there would be great changes in the intervening spaces.

THE RATE OF SECULAR INCREASE OF THE ALLUVIAL LAND.

I shall now proceed to consider the geological conclusions which appear to me to be fairly deducible from the facts which these researches have disclosed, with reference to the object for which they were undertaken, viz. to endeavour, by digging deep into the soil at appropriate places, to ascertain how nearly we can determine the rate of secular increase of the alluvial land by the sediment left upon it annually by the inundation, and thence to form a probable estimate of the time that has elapsed since the lowest part of the sediment to which we could reach was deposited. But before entering upon this part of my memoir, it is necessary that I should draw attention to the inquiries of a similar nature which were instituted by the French Engineers who accompanied the expedition under General Bonaparte at the close of the last century, as recorded in the celebrated work, the 'Description de l'Égypte.'

In books that have appeared since the publication of that great work in 1809, when the formation of the alluvial land of Egypt is referred to, it is generally assumed as a settled point, that the mean increase of that land has been at the rate of 5 inches in a century, all over the valley from Assouan to Cairo*. The authority relied upon is the

* Thus, for example, M. Elie de Beaumont, in his 'Leçons de Géologie Pratique,' published in 1845, p. 480, says,—"dans la Vallée d'Égypte, l'exhaussement du sol est moyennement d'environ 126 millimètres (4·960 inches) par siècle."

memoir of M. GIRARD in the above work, afterwards published in the Memoirs of the Institute*. I have been naturally led to examine very carefully the data upon which the result arrived at by M. GIRARD was founded, and have seen reason to differ from his conclusion. In thus differing from an authority sanctioned, apparently, by the assent of subsequent authors for so long a time, although that assent may have been given without special examination, I should not feel justified in expressing my dissent, without stating the grounds of it, and without giving such extracts from M. GIRARD's memoir as will show the data on which his conclusion is founded. This must be my apology for a somewhat lengthened statement which I have given in the Appendix, Note C, p. 80.

The statement of a *mean* secular increase of the soil over a valley extending 580 miles, even if it were determined by the most accurate data, gives us no information of real value; for that mean may be inapplicable to any one particular part of the valley; and it is especially inapplicable in relation to the geological history of the alluvial land, when a depth of one foot of soil in one place and of three feet in another, might, according to circumstances, have been deposited during the same amount of time, the object of inquiry being to ascertain the probable age of the lowest layer of the Nile sediment. In every situation where the experiment is made, we must have *a fixed point in time* to start from, viz. the known age of a monument whose foundation rests upon Nile sediment, and upon whose sides it has accumulated by subsequent inundations. If there have been no local causes to disturb the probability that the sediment above and below the foundation has accumulated at the same rate, we divide the amount above the foundation by the number of centuries known to have elapsed from the erection of the monument to the present time, and then apply the same chronometric scale to the greatest ascertained depth of sediment below the foundation. If many experiments were thus made in different localities throughout the valley, where monuments of a known age exist, upon whose sides the sediment had accumulated and whose foundations were ascertained to rest upon the same kind of sediment, we should obtain reliable results, applicable to the valley generally. But in no one locality, however deep the sediment, could we affirm that we had reached the oldest layer, unless it rested on limestone (the rock foundation of the valley), because of the more than probable inequality of the surface of its bottom. We might arrive at a very high antiquity, but we could not say that we had arrived at the highest. To divide a depth of sediment above the foundation of a monument by *an assumed mean secular increase of it over the whole valley*, and thence to determine, as has been done, the age of the monument, is obviously, for the reasons stated, a fallacious inference.

* Sur la Vallée d'Égypte, et sur l'exhaussement séculaire du sol qui la recouvre; Mémoires de l'Académie Royale des Sciences de l'Institut, année 1817.

How far a local secular rate of increase of the alluvial land may, with probability, be estimated from these recent researches.

The Obelisk at Heliopolis and the colossal statue of RAMESSES II. on the site of Memphis, are the only monuments of high antiquity, and of a known age, upon and around which the sediment of the inundations has accumulated, in that part of Lower Egypt where alone it was practicable to undertake the researches described in this memoir, viz. in the vicinity of Cairo.

In the excavations made around the Obelisk of Heliopolis, it was found in that nearest to it (A)* that the surface of the pedestal on which the obelisk stands was reached at a depth of 5 feet 6 inches, and that the pedestal measured 6 feet 10½ inches in height, making together 12 feet 4½ inches from the surface of the ground to the foot of the pedestal. But we may presume that the pedestal, at the time of its erection, would be sunk somewhat below the then surface of the ground, and if we allow for that 1 foot 4½ inches, we have an accumulation of sediment of 11 feet from the present surface of the ground to the level where the pedestal first appeared above the surface, at the time of the erection of the obelisk.

The obelisk is believed to have been erected 2300 years B.C.†, and adding 1850, the year when the observation was made (June 1851, *i. e.* before the inundation of that year), we have 4150 years in which the 11 feet of sediment were deposited, which is at the rate of 3·18 inches in a century.

But entire reliance cannot be placed on this conclusion; and this very ancient monument of known age, apparently so well calculated to solve the problem, from unforeseen circumstances in the nature of the ground on which it was erected, has failed to afford the true chronometric scale which it was hoped it would have done. For there is great uncertainty whether the 9 inches of "disturbed ground" is entirely true sediment, and also whether the sand that was reached before coming to the base of the pedestal was deposited by the Nile, or was original desert ground, that had been sunk into for the foundation. I have already stated‡ that the appearances round the obelisk render it probable that the site originally chosen for the temple and city of Heliopolis was a portion of land somewhat raised above the level of the rest of the skirt of the desert, and advancing into the low grounds then inundated by the Nile. This view is supported by the differences in the nature of the soils passed through in the excavations to the west of the obelisk, that is, nearer to the Nile, from those to the east of it, especially the excavation H, which was due east, and therefore on the supposed offshoot from the desert land. Thus,

In the excavation B, 100 yards west of the obelisk, there was found 13 feet 3 inches of mud (argillaceous sediment); in C, 784 west, 14 feet 3 inches of mud, which in neither pit was gone through, as the filtration water prevented further progress.

In the excavation D, 270 yards south-east, there was found 12 feet 5 inches of mud,

* These excavations are described in Part I. of this Memoir, from page 131 to 136.

† Id. page 123. ‡ Id. page 123.

and then 2 feet 10 inches of quartzose sand. In E, 100 yards north-east, 12 feet 6 inches of mud, and then 1 foot 7½ inches of quartzose sand, which was probably blown sand, as below it there was a repetition of 3 feet 7 inches of mud. In F, 383 yards north-east, there were 8 feet 1½ inch of mud, and then 2 feet 2½ inches of sand. In G, 1215 yards north-east, there were 6 feet 8 inches of mud, and 8 feet 4 inches of sand. In H, 615 yards due east, there were only 2 feet 10 inches of mud, and then 11 feet 8 inches of sand.

The Colossal Statue.

In the excavation at this statue in the area of Memphis in 1852, the level of the upper surface of the platform on which the statue had stood was ascertained to be 5 feet 8 inches below the surface of the ground; but as there were 8 inches of a sandy earth, there remained 5 feet of true Nile sediment. The upper blocks of the platform are 31½ inches thick, and the lower 35½ inches, together 5 feet 6¾ inches. If we allow the lower part of the platform to have been 14¾ inches below the surface of the ground at the time it was laid, we have a depth of sediment from the present surface of the ground to that level of 9 feet 4 inches. RAMESSES, according to LEPSIUS, reigned from 1394 to 1328 B.C., and if we suppose the statue to have been erected in the middle of his reign, *i. e.* in 1361, we have between A.D. 1854 and that time 3215 years, during which the above depth of 9 feet 4 inches of sediment was accumulated; and supposing that no disturbing cause had interfered with what may be termed the normal rate of deposition *in this locality*, and of which there is no evidence, we have thus a mean rate of increase within a small fraction of 3½ inches in a century.

The depth of ground excavated in the second pit, close to the statue of RAMESSES II., in 1854, was 24 feet, and the additional depth examined by boring was 17 feet 4½ inches, together 41 feet 4½ inches. Of this total, 9 feet 4 inches have been assumed to have been deposited between 1361 B.C. and the year 1854, and thus we have a remainder of 32 feet of the total depth penetrated. But the two lowest feet consisted of sand, below which it is possible there may be no true Nile sediment in this locality, and we have thus 30 feet of the latter. If that amount has been deposited at the same mean rate of 3½ inches in a century, it gives for the lowest part deposited an age of 10,285 years before the middle of the reign of RAMESSES II., 11,646 years B.C., and 13,500 years before A.D. 1854.

The deeper parts of this accumulation of 30 feet of sediment are probably more compact in structure from the long-applied superincumbent pressure, and therefore their age is probably greater, on that account, than that arrived at by the application of the chronometric scale of 3½ inches in a century, obtained by measuring the superior and specifically lighter part of the accumulated mass.

The other excavations and pits, both those in the parallel of Memphis and those in the parallel of Heliopolis, from the absence of a fixed starting-point of known age, with accumulations of Nile sediment above and below it, as in the case of the platform of the colossal statue, do not supply us with the requisite data for estimating the age of the

lowest part reached, beyond a reasonable inference in each case, according to the circumstances of the particular locality. But they have supplied a large and valuable amount of evidence, showing the nature and alternations of the soils constituting the alluvial land; and, taken in conjunction with the researches of a similar nature made by the French engineers at the end of last century, a brief account of which I have given in the Appendix, p. 84 (Note D), they afford strong presumptive evidence that the whole of the land of Egypt between the bounding hills, from the first cataract to the sea, extending nearly 700 miles—that land which is associated in our minds with all that is most ancient in history or tradition—belongs entirely to the recent geological period. Remote as is the date of 13,500 years from the present time which these probings of the soil appear to have disclosed, they have not enabled us to attain the hoped-for object of discovering an approximate link between historical and geological time. No trace of an extinct organism has been turned up to take the formation of the alluvial land of Egypt beyond that modern epoch from which, in our artificial systems, we are used to carry back our geological reckonings; that period, which, although "characterized as the most recent, reaches to an infinitely higher antiquity than any contemplated by history or fable*." Evidence might possibly be found in the valley, by well-directed researches, which would approximatively determine the commencement of the recent period in this region, but all experience in geological inquiries hitherto would lead us to expect that the discovery would show a vastly remote antiquity. That the valley of the Nile in Egypt was formed by an internal movement in the earth's crust, which broke up horizontally deposited strata and produced the depression, scarcely admits of a doubt; and, from all that we have hitherto discovered, it is probable that the depression was partly filled up by sand, blown from the adjacent high lands, before the waters of the Nile were directed into it, and that these sands form the bed on which the sediment began to accumulate.

Evidence which these researches would seem to afford of a very early existence of Man in Egypt.

In a large majority of the excavations and borings, the sediment was found to contain, at various depths and frequently at the lowest, small fragments of burnt brick and of pottery. In the lowest part of the boring of the sediment at the colossal statue in the year 1854, at a depth of 39 feet from the surface of the ground, consisting throughout of true Nile sediment, the instrument brought up a fragment of pottery, now in my possession. It is about an inch square and a quarter of an inch in thickness, the two surfaces being of a brick-red colour, the interior dark grey. This fragment, having been found at a depth of 39 feet, if there be no fallacy in my reasoning, must be held to be a record of the existence of man 13,371 years before A.D. 1854, reckoning by the before-mentioned rate of increase in that locality, of 3½ inches in a century; 11,517 years before the Christian era, and 7625 years before the beginning assigned by LEPSIUS to

* Rev. BADEN POWELL, 'Christianity without Judaism,' p. 57.

the reign of MENES, the founder of Memphis; of man, moreover, in a state of civilization, so far, at least, as to be able to fashion clay into vessels, and to know how to harden it by the action of a strong heat *.

In the pit marked No. 6 in the Ground Plan at page 62, which was 354 yards north of the colossal statue, at a distance of 330 yards from the river, fragments of pottery were found at a depth of 38 feet from the surface of the ground.

Fragments of burnt brick and of pottery have been found at even greater depths in localities near the banks of the river, ten and sixteen miles below Cairo. In the boring at Sigiul, described in page 64 under the number 26, fragments of burnt brick and pottery were found in the sediment brought up from between the 45th and 50th foot from the surface, and in the boring at Bessousse, they were brought up from the lowest part, viz. 59 feet from the surface, but in this case in sand, the lowest sediment containing fragments of brick and pottery being at a depth of about 48 feet. I have also learned, from a communication with which I have been favoured by M. LINANT DE BELLEFONDS (LINANT BEY), that a few years ago he made a boring about 200 metres (656 feet) from the river on the Libyan side of the Rosetta branch of the Nile, in the parallel of the apex of the Delta, and that he had found fragments of red brick at a depth of about 72 feet below the surface of the ground. But in these cases there was wanting the fixed point of known age, the indispensable requisite for the formation of a chronometric scale. I may, however, state that M. DE ROZIÈRE † estimates the mean rate of the deposit of the sediment in the Delta, as not exceeding 2 French inches and 3 lines (60,907 millimetres=2·3622 English inches) in a century ‡.

The lowest water in the Nilometer of Rhoda in the year 1847, was determined by M. TALABOT to be 46 feet 2 inches above low water in the Mediterranean §. The fall of the river between Cairo and the apex of the Delta is $3\frac{3}{4}$ inches in a mile ‖, and Sigioul and Bessousse being about 10 miles below the Rhoda Nilometer, the lowest water in the river in those localities would be about 43 feet. It is thus evident that the fragments of red brick and pottery found in the sediment brought up by the borings in those places, must have been, if not below, a very little above low-water mark in the Mediterranean, and that the fragments of brick found at so great a depth by LINANT BEY must have been considerably below that mark. It is therefore most probable that the fragments found in these localities were brought down by the river from the higher and inhabited part of the valley, at a time previous to the formation of the Delta.

There is every reason to believe that the whole of the area now occupied by the allu-

* For the opinion of the Baron VON BUNSEN as to the very early existence of man in Egypt, see Appendix, page 86, Note E.

† Description de l'Égypte, Hist. Nat., tome ii. p. 494.

‡ The question of the formation of the Delta is very fully examined by M. ELIE DE BEAUMONT, in his 'Leçons de Géologie,' tome i. pp. 405–492. The appearances in some parts of the coast, which have led some authors to suppose them to be indications of a depression of the land, are considered by M. DE BEAUMONT as insufficient proofs of such an event.

§ Memoir, Part I. p. 114. ‖ Id.

vial land of Lower Egypt, the Delta, was at one time a bay in the Mediterranean, which in the course of ages was gradually filled up by deposits from the numerous branches of the Nile not confined by artificial embankments, and aided by sand blown from the adjacent high desert land *; and that at a time when the shore of the bay had advanced first to the parallel of Sigioul and Bessousse, and afterwards to that of the present apex of the Delta, by means of the accumulations at the embouchure of the Nile, the fragments of brick and pottery that had fallen into the river above were carried forward by it into the bay. This process appears to have continued as the shores of the bay gradually advanced northward, even to its present sea-line; for in borings made by HEKEKYAN BEY in 1854 at Sa-il-Hagiar, a village about 45 miles above Rosetta, the supposed site of the ancient city of Sais, and also in the neighbourhood of Rosetta itself, similar fragments were found at depths of 19 and 20 feet. He states that rubbish soil extends to considerable depths under the foundations of stone buildings below the lowest level of the Mediterranean, and quite close to the sea.

* "There must have been a time when the Delta was not only a marsh, but was even covered with water; and when the sea must have advanced so near to the site of Memphis, as to allow the annual flood to rise no higher than 8 cubits, or 12 to 14 feet at that place. HERODOTUS afterwards remarks, that it rose 15 or 16 cubits in his time, which was the natural progress of things, as the point of contact of the *land* waters with those of the *sea* was removed further out."—RENNELL's 'Geography of HERODOTUS,' 112.

APPENDIX.

APPENDIX.

Note A, page 54.

That a subject of the Grand Sultan, and one resident in Egypt, should be distinguished by attainments in science and literature is so rare an occurrence, that the Society may naturally expect me to give some biographical notice of my friend and coadjutor in this work, HEKEKYAN BEY. Had I not been so fortunate as to make his acquaintance, my object could not have been attained. Such extensive operations could not have been undertaken by a European, by any one not thoroughly inured to the climate of Egypt, nor by any one unacquainted with pursuits in physical science, and who was not familiar with the language of the numerous persons to be employed, of whom a large proportion must be common labourers. The researches had to be carried on under a burning sun, and they were continued during three years. My correspondence with HEKEKYAN BEY has been going on for more than five years; he writes English like a native, and it would be difficult for me to over-rate the value of his unwearied cooperation.

He is a native of Constantinople, of an Armenian Roman Catholic family. His father, MICHIRDIZ, was in the service of MEHEMET ALI, Viceroy of Egypt, in the capacity of translator of political or other useful dissertations for the personal use of the Pacha; being equally conversant with the Turkish and French languages.

MEHEMET ALI having resolved on sending the sons of several of his officers to Paris for their education in the year 1817, MICHIRDIZ solicited, as a reward for his services, that his son might be sent for the same purpose to England, and his request was granted. HEKEKYAN was then living with his family at Constantinople, and was only ten years of age. When he arrived in London, the only language he knew was the Turkish. He was placed under the care of Mr. BRIGGS, formerly British Consul at Alexandria, who had returned to England*; and to enable him to continue in the religion of his family, he was placed at the College of Stonyhurst in Lancashire. Here he received the first elements of an English education. After completing at the College the usual course of studies, as it was the desire of the Viceroy that he should be instructed in the management of steam-engines and machinery, he was placed by Mr. BRIGGS with Mr. BRAMAH, with whom he remained between two and three years. The Viceroy next desired that he should turn his attention to the machinery employed in cotton mills, as MEHEMET ALI wished to establish that manufacture in Egypt, and he was, accordingly, a considerable time at Manchester and Glasgow. The Viceroy was not yet satisfied, but required him to be instructed in hydraulics, and an eminent engineer in London received him as a pupil, taking him with him while engaged in the formation of some canals and other works.

After a stay of twelve years in England, HEKEKYAN returned to Egypt in the autumn of 1830; but unfortunately he had forgotten his native tongue, and as he could only

* To this gentleman I am indebted for most of the particulars here given.

communicate with his patron the Viceroy through the medium of an interpreter, it proved, at first, a great obstacle to his advancement. For three years MEHEMET ALI employed him to superintend his cotton mills, but in 1833 he was appointed to a more congenial occupation, being entrusted with the organization of the Polytechnic School in Cairo, receiving rank as an Adjutant on the Staff, and in 1835 the advanced step of Major of Engineers. He established *l'École des Arts et Métiers*, which he continued to direct to the end of 1840, by which time he had obtained the rank of Lieut.-Colonel. During the seven years that he was attached to that school, he was more or less engaged in almost all the commissions appointed by his Government to examine the plans proposed for the construction of roads and bridges, fortifications and the working of mines; and he was further engaged to translate into Turkish, for the use of the Viceroy, the more important articles in the journals of England, France and India. He was now advanced to the rank of Bey in the Engineers, and after being engaged in several employments in the public service, early in 1850 he retired into private life.

Note B, page 61.

The existence of Microscopic Organisms in the Nile sediment.

I sent some specimens of recent sediment and of some brought up from a considerable depth, in all sixteen, to my friend the late Dr. MANTELL, requesting him to examine them under his powerful microscope. He did so, and his report was,—"Not a vestige of organisms of any kind have been detected. I never before found any fluviatile detritus free from animal or vegetable remains of some kind or other." Accidentally mentioning this to my friend Professor C. RITTER, then in England, he expressed much surprise, as Professor EHRENBERG had published some years ago an account of many forms he had found in Nile sediment, and he requested me to send some of the same which had been examined by Dr. MANTELL to Professor EHRENBERG. I did so, and the Professor kindly undertook a careful examination of them. The results he read at a meeting of the Berlin Academy, and they are published in their 'Monatsbericht' for 11 November 1852. He then describes his having found in the sixteen specimens, 67 organisms; viz. 10 Polygastrica, 47 Phytolitharia, 4 Polythalamia and 6 indeterminate forms. The details of forty-four examinations are given.

Two years afterwards, being in Berlin, I requested Professor EHRENBERG to show me some of the numerous organisms he had found; they are preserved in his collection, and are for the most part figured in his great work, '*Geologie des kleinen Lebens.*' Many of the plates I had then before me, and I selected, at a venture, those which I wished him to show me. He brought them out, and I saw, with a power of 300, with perfect distinctness, the following, which are figured in the above work:—

POLYGASTRICA.

Surirella Rhopala, Tafel xxxiii. I. 19. Taf. xxxv. A. x. 3.
Gallionella procera, Tafel xxxiii. I. 12. Taf. xv. A. 1.

Trachelomonas granulata, Tafel xxxv. A. 13.
Eunotia amphioxys, Tafel xiv. 31. Taf. xxxix. 29, 30.

PHYTOLITHARIA.

Lithostylidium rude, Tafel III. III. 21.
Lithostylidium quadratum, Tafel xxxiv. VI. 6.
Lithostylidium spinulosum, Tafel xxxv. A. XIV. 6.
Lithostylidium Trabecula, Tafel xxxiv. VI. 8.
Lithodontium nasutum, Tafel xxxix. 61, 62.
Lithodontium rostratum, Tafel I. III. 25.
Spongolithis acicularis, Tafel I. I. 16.
Spongolithis, Tafel xxxiv. V. B. 16.
Spongolithis, Tafel x. 22.
Spongolithis, Tafel xiv. 109.

Note C, page 72.

M. GIRARD'S *estimate of the Secular Increase of the alluvial land.*

His conclusions were founded on observations made at the ruined Nilometer on the island of Elephantina, near Assouan, and afterwards at the existing Nilometer on the island of Rhoda near Cairo.

He visited Elephantina towards the end of July 1799, and found at the shore a wall or quay 160 metres (525 feet) in length, and in a part of it a gallery and chamber, and from the latter a staircase leading down to the river. On cleaning the walls of this staircase, he observed upon them four vertical grooves cut into the stone to a depth of a centimetre (about $\frac{4}{10}$ths of an inch) with horizontal divisions, which proved to be marks of cubits, some of them having numbers annexed to them. He had thus no doubt that he had found the Nilometer. "The last cubit," says M. GIRARD, "of this Nilometer is marked in Greek characters with the number 24; that was, in effect, Egyptian cubits, the use of which was continued, as we know, under the Ptolemies, indicating the height of great inundations, as measured immediately below the last cataract. At the time, therefore, when the Nilometer was constructed, the inundations did not rise beyond that mark. ..... To compare the level of the twenty-fourth cubit of this Nilometer with that of the highest recent inundations, it was necessary to know the height to which the latter rise at this place, and fortunately the marks they leave are not obliterated from year to year, and we observed them very distinctly on the face of the wall of the quay, behind which the scale of the Nilometer is traced. The result of the levelings I took, to determine the space between the twenty-fourth cubit of the Nilometer and the level of the highest inundations of the present time, showed a difference of 2·413 metres (7 feet 11 inches). Thus, the bed of the Nile has risen by that amount, at least, between the time when the Nilometer was erected, for there is no reason to think that the

quantity of water coming from Abyssinia is different now from what it was then. An inscription in Greek characters traced in the wall of the Nilometer has the date of the reign of SEPTIMIUS SEVERUS, and the object of it seems to have been to mark an inundation that had risen several palms above the twenty-fourth cubit. It is probable that the inundation referred to was not an extraordinary one, but that the Romans who formed the garrison at Syene in that reign, ignorant of the effect of the natural rise of the bed of the river, noted it as a remarkable event, supposing that the highest point of the twenty-fourth cubit was a fixed point, beyond which the annual flood of the river could never rise. Now admitting the highest inundations to have reached the mark traced above the twenty-fourth cubit, that is to say, that they had risen above it about 0·31 metre (12·205 inches) at the date of the inscription, it will be easy for us to fix the amount by which the bed of the Nile at Elephantina has been raised between that epoch and the present day. Thus, SEPTIMIUS SEVERUS became Emperor in A.D. 193, and died in 211, and supposing the inscription to have been cut on the stone in the middle of his reign, the bed of the Nile will have risen 2·11 metres (6 feet 11 inches) in 1600 years, which gives 0·132 metre (5·192 inches in a century)."

M. GIRARD then gives the observations he made, with the same object, at the Nilometer on the island of Rhoda near Cairo, which he states to have been reconstructed about A.D. 847. "There can be no doubt," he says*, "that at the time when this Nilometer was erected, its 16th cubit by which it is terminated indicated a year of plenty, for it has always been of importance for the government to know the extent of the rise of the inundations, by which they could levy the largest amount of duty. If therefore the inundation had risen higher than the existing Nilometer, it is evident that they must have added to the height of the column, in order that it might show the inundations the most favourable to the exchequer. Now, in the present day, if the Nile does not rise above the 16th cubit of the Mekyas (Nilometer), it is considered unfavourable. That of 1799, for example, was considered to be one of the least favourable, and yet it rose to 16 cubits 2 digits. But the following year was one of plenty, and the water had risen to 18 cubits and 3 digits, thus making a difference of 2 cubits and 3 digits between the highest rise at the time of the erection of the Nilometer, and that to which it had risen in 1800, or 1·149 metre (45·237 inches) in 953 years, which is equal to 0·120 metre (4·742 inches) in a century." The difference between 0·132 at Elephantina and 0·120 at Rhoda may, he considers, be accounted for by possible changes in that distance, in the inclination of the bed, the amount and velocity of the stream, and its wearing power on the banks; but that it is so slight, that the secular rise of the bed of the river may be very nearly represented by the mean of the above sums, that is 0·126 metre, or 4·960 inches.

He then comes to a conclusion which I shall give in his own words:—"Quant à l'exhaussement moyen du sol de la vallée d'Égypte, il suffit d'une légère attention pour reconnaître, qu'il doit être exactement le même que l'exhaussement moyen du lit du Nil."

* *Loc. cit.* p. 264.

"Si donc il n'est point exact de dire qu'en un point déterminé de l'Égypte, le fond du lit du Nil et la plaine adjacente s'élèvent simultanément de la même quantité séculaire, il est constant que, depuis la dernière cataracte jusqu'à la mer, le fond du fleuve et le niveau des plaines qu'il submerge se sont élevés d'une même quantité moyenne, puisque ces deux surfaces tendent sans cesse au parallèlisme, et que la nature les y ramène quand des circonstances particulières ou les travaux des hommes les en ont momentanément écartées*."

The data upon which M. GIRARD founds his conclusion appear to me to be far too loose and indeterminate in their nature, and insufficient in number, to warrant the establishment of what may be termed a law of increase. Some observations are stated to have been made at Thebes, Siout, Heliopolis, and some other places, with the view of testing the accuracy of this rate of secular increase, by digging into the alluvial soil at the foot of ancient monuments, applying to remote antecedent periods the rate which had been founded upon observations which had reference only to comparatively recent times; but in none of those cases was any definite result obtained confirmatory of the assumed rate.

As regards the observations at the Nilometer of Elephantina, they are accompanied by some sources of uncertainty. In the more than 2000 years between its erection† and the time of M. GIRARD's observations, it is far from improbable that the foundation of the building may have sunk, an occurrence by no means rare, and which, it is believed, has happened to the Nilometer of Rhoda. It is *assumed* only that the figure 24 marked the highest inundations at the time of the formation of the scale; it is *assumed* that the mark and inscription had been made by the Roman garrison with the intention of recording the highest flood at that period. The mark on the external wall is not a perfectly reliable proof of the height to which the inundations in recent times may have reached, as it may have been caused, so near the cataract, by some temporary and purely local accumulation of the water. After the river has attained its stationary salibe level, it sometimes continues to rise several inches higher, on account of occasional and sudden torrents falling into the Nile valley by some of the numerous side ravines, which bring down the rain-water from the Arabian or Libyan Hills; rain-clouds with thunder and lightning frequently cross the valley, coming generally from the west, and the rain falls very heavily.

As regards the Rhoda Nilometer, it is difficult to comprehend how there should have been so trifling a difference between the relative proportions of secular increase at Elephantina and Rhoda, viz. 0·132 metre and 0·120 metre, from which M. GIRARD makes the mean secular rise of the bed of the river 0·126. I have already shown how, from various causes, there must be a progressive diminution in the amount of sediment as the

* *Loc. cit.* p. 266.

† "Quant à la construction de cet édifice, je ne crois pas qu'on puisse en faire remonter la date au delà les Ptolemées. Les caractères numériques qui distinguent chaque coudée prouvent qu'il est l'ouvrage des Grecs."—GIRARD, Description de l'Égypte, Antiq. Mémoires, tome i. p. 11.

river descends, and in a distance of 580 miles the difference at the extremes of Cairo and Elephantina must be very great. Under such circumstances, that the rise of the bed of the river and the rise of the inundation water at the two places should relatively have so near an agreement, appears to me to be highly improbable.

It is further assumed that the Rhoda Nilometer has undergone no alteration since A.D. 847; but M. MARCEL, a colleague of M. GIRARD in Egypt, in an elaborate dissertation on this Nilometer*, states, that it was erected in A.D. 715, that it had been injured by neglect, was restored in 814, repaired in 846, and again repaired in 861, 1092, and 1518. Sir GARDINER WILKINSON tells us "that it is certain no accurate calculations can be obtained from a column which has been broken and repaired in such a manner that one of the cubits remains incomplete†." How little reliance, for such an object, is to be placed on this Nilometer, is still more apparent from the following extracts from a memoir upon it sent to me by HEKEKYAN BEY, dated Cairo, 15 November, 1857.

"The chamber or deep basin in which the graduated column is erected, is an oblong space 21 feet 8 by 16 feet 9, having a flight of steps within it. The present column is formed out of the remnants of an older column of records, erected formerly on the same spot. According to some historians it was commenced and terminated in A.D. 715. The building has frequently required repair, effected at various intervals by Caliphs, Sultans, Beys, Pachas, and by the French General MENOU. It rests upon an isolated disk of sandstone 31½ inches thick, and by soundings it has been ascertained that the disk rests upon an arenaceous Nile alluvium, containing particles of limestone and pottery.

"In estimating the heights of the inundations by the column, the difficulty to surmount has been, the conception of some clear idea of the nature of the scale and the nomenclature used in the daily measurements and records of the water-levels. At the bottom of the flight of steps there is a landing-place, called the Mastaba, the surface of which is on a level with the 9th cubic mark on the column. The surface of the water at the commencement of the annual increase is measured down from the Mastaba, and when it has risen to that level, it is measured up from the Mastaba until it culminates. It is again measured down from its point of culmination to the Mastaba, and from that level down to its ebb, and again down from the Mastaba at the rise of the following year, circularly, without intermission; a process which has been going on from generation to generation every day at sunrise, and with extreme care at the precise times of the two solstices and equinoxes. These measurements are carried up and down the interior scarps of the walls of the chamber on the west and south sides. The measuring instrument is the Black Cubit, so called because it is made of ebony.

"The column has nothing to do with these measurements. MEHEMED ALI PACHA, observing the wide discrepancies between the numerical values assigned evidently to the same water-levels from year to year, ordered the Sheikhs of the Nilometer to send up the daily accounts of their observations, and to register them in government books.

* Description de l'Égypte, tome i. p. 29, and tome ii. État Moderne, p. 119.

† Topography of Thebes, p. 313.

"In 1852, the Sheikh of the Nilometer attending on me by order of the late Viceroy, informed me that the Mastaba was the 9th cubit, that he measured from it 7 cubits to obtain the 16th and three more to get at the 22nd, and two more to reach the 24th. Accordingly from the 9th to the 24th we have 12 cubits, and nine more below the Mastaba. I wished the Sheikh to afford me further information, which he declined, affirming that he was engaged by a sacred promise, like all his predecessors and ancestors,—the office is hereditary—to reveal the secrets of the Nilometer to no ear but that of the reigning Caliph of the Faithful. On my requesting, however, that he would show me how he measured up to the 24th cubit, he indicated a point on the parapet, which I measured, and found to be 254·209 inches above the Mastaba, which at 20·625 inches to the cubit, instead of 15 cubits, is only 12·325.

"The cubit divisions on the column do not at all correspond with the standard of 20·625, for on measuring the seven cubits between the 9th and 16th, I found it to be 155·20 inches, which gives 22·17 inches to the cubit. From the Mastaba to the upper surface of the sandstone disk on which the column rests, that is, the *nine* cubits, the distance was found to be 148·67 inches, which gives only 16·52 inches to each cubit. From the base of the column to the 16th cubit mark we have thus 303·87 inches, which gives an average of 18·99 to each cubit.

"The conflicting statements made by the Sheikhs of the Nilometer induced the French savans to give up the question of the scale used by the Ulema, and to adopt a new system of their own invention for future annual observations and records. The extraordinary high Nile of the 4th of October 1804 was quoted by the Ulema at 14 cubits and 17 digits; but the same water-level by the French measurement amounted to 18 cubits and 3 digits. On the 23rd of September 1799 the water-level was recorded by the Ulema at 12 cubits and 16 digits, and by the French at 16 cubits and 2 digits, and on the 8th of October 1798 the Ulema quoted 14 cubits, and the French 17 cubits and 10 digits."

Note D, page 75.

The researches undertaken by the French engineers, for the purpose of ascertaining the nature and depth of the alluvial soil in the Nile valley in Upper Egypt, are described by M. Girard, under whose special direction they appear to have been conducted *.

The first excavations were made in the early part of April 1799, in the nearly level plain in which Siout is situated, about 240 miles above Cairo. The valley here is rather more than six miles in width, the Nile flowing nearly two miles from the western or Libyan range of hills. Eleven pits were sunk in a continuous line from the Libyan Hills to the left bank of the river, and two, XII. and XIII., on the right bank, in a prolongation of the same line.

* Sur la Vallée d'Égypte, &c., Mémoires de l'Institut, 1817.

Pit.	Distance from the former pit.		Mud.		Sand.		Total depth of the pit.	
	yds.	ft.	ft.	in.	ft.	in.	ft.	in.
I.	.....		13	0	.....		13	0
II.	218	2	20	11½	4	1¼	25	0¾
III.	393	2	20	5¼	7	2½	77	7¾
IV.	142	0	11	0	6	0		
V.	153	0	11	0	9	3	20	3
VI.	437	1	4	3	6	6¾		
VII.	236	0	4	6¼	16	10	21	4¼
VIII.	235	0	4	11	13	0		
IX.	345	1	8	2¼	11	5¾	19	8
X.	332	1	7	8½	10	6½	18	3
XI.	393	2	7	4¼	20	10	38	2¼

In the pits X. and XI., at the level when the filtration water prevented further excavation, a boring tool was applied, and what it brought up showed that the same sand continued at a further depth of 16 feet.

The pits XII. and XIII. were sunk on the right bank; XII. at its edge, which rose above the highest inundation level. They first passed through 27 inches of pure mud (*limon*), which rested on 107 inches of micaceous sand mixed with a little mud, below which there were 85 inches of grey sand, and 4¼ inches of magnetic iron sand; lastly, 60½ inches of a mixture of sand and mud, when they were stopped by the filtration water. Thus—

Pit XII.

	ft.	in.
1. Pure mud	2	3
2. Micaceous sand	8	11
3. Grey sand	7	1
4. Iron sand	0	4¼
5. Sand and mud	5	0½
Depth of pit	23	7¾

Pit XIII.

Was sunk near to a broad canal 916 yards east of No. XII. They found—

	ft.	in.
1. Pure mud	20	9
2. Ferruginous sand	4	0
Depth of pit	24	9

Being desirous of reaching, if possible, the rock which forms the base of the valley, they sank a pit in the same locality, but in the vicinity of the bounding hill, 304 yards from the cultivable land. They chose a projection of the base of the hill, which they conceived would be composed of the gravel that constitutes the soil of the desert land. The result of their excavation was—

	ft.	in.
1. Sand and gravel	6	10
2. Yellow sand mixed with clay, forming a very compact mass	8	0
3. Whitish marl	0	8½
4. Pure incoherent yellow sand	1	10
5. Whitish marl	0	8½
6. Sand, gravel and rolled pebbles	3	11
	22	0

At this depth they struck a bed of limestone, the same as that in which the grottos of Siout are excavated, and they inferred that thus the limestone beds dip towards the river beneath the alluvium.

Their next excavations were in the vicinity of Queneh, about 140 miles above Siout; and here they sank two pits on the right bank of the river:

No. I. 554 *yards from the Nile.*

	ft.	in.
1. Mud	8	10
2. Grey sand	15	6
Filtration water at	24	4

No. II. 187 *yards from the Nile.*

	ft.	in.
1. Mud	4	7
2. Grey sand	24	9½
Filtration water at	29	4½

Their next excavations were at Esneh, about 90 miles above Queneh, and about 100 below Assouan. They sank three pits on the right bank, and three on the left, with the following results:—

Right bank.				Left bank.			
Pit.	Mud.	Sand.	Filtration water reached at	Pit.	Mud.	Sand.	Filtration water reached at
	ft. in.	ft. in.	ft. in.		ft. in.	ft. in.	ft in.
I.	16 0½	8 11	24 11½	I.	19 8	.....	19 8
II.	18 8½	8 0	26 8½	II.	15 10	5 11	21 9
III.	24 6	.....	24 6	III.	12 5½	7 3½	19 8¾

I. 249 yards from right bank of river.

II. 1312 yards from I., nearer the Arabian Hills.

III. 1312 yards from II., further inland, and on the boundary of the cultivable land. Filtration water was reached before they had penetrated through the mud.

The plain rises about 3 feet 3 inches from the Nile to the foot of the hills, and the cultivable land extends 1¼ mile from the river.

I. 3609 yards from the Nile, at the outer edge of the cultivable land. No sand was reached.

II. 1640 yards from I., and so much nearer the river.

III. 656 yards from II., and so much nearer the river.

NOTE E, page 76.

The Chevalier BUNSEN, in his 'Egyptens Stelle in der Weltgeschichte,' has the following passage:—

"It may be assumed as a settled point in history, that Egyptian tradition, prior to MENES, admitted one dynasty of kings in Lower Egypt, and one at least, perhaps two, in Upper Egypt, during a period of from 2000 to 4000 years. The race of MENES succeeds three dynasties. They are perfectly distinct from the mythical kings, whose history is connected rather with that of the Gods. MENES united the Upper and the Lower Country."—English Translation, Book I. pp. 71, 72.

In the preface to the Fourth Book of the same history, published in 1856, there occurs the following passage:—

"An examination of the time from ALEXANDER to MENES, and of the vastly remote

contemporaneous events of Asiatic life, leads us to documentary beginnings of a great development, more or less chronologically determinable. But when we come to consider more closely the unmistakeable purely historical time, before MENES, of separate kingdoms and particular provinces, we discover that those earlier ages belong to a period, when the foundation of that entire development rested upon the formation of language and mythology. The author believes that he is justified in maintaining this to be a fact in historical science."

"Records forming a documentary history of nations extend to about 4000 years before our era, and an early period of long duration must necessarily have preceded these. When, on the grounds set forth in our Fifth Book, we assign to that period a duration of from 6000 to 9000 years for Egypt, and from 15,000 to 16,000 years for man's existence, it is no arbitrary and presumptuous application of research, but an emancipation of ourselves from error which throws everything into confusion. The first epochs of the history of the human race demand, at the least, a period of this extent, and its commencement, 20,000 years before our era, is a fair starting-point in the earth's history." —Original edition, Vorrede, p. viii.

*Tables of the Soils**.

Signs in the sections.	Varieties.	Local names given by HEKEKYAN BEY.
A.	Blackish brown argillaceous earth, similar to sample I. Memoir, Part I. p. 130	Teane zebedi, butter soil or fine clay.
B.	Blackish, argillaceous sandy earth	Teane soda iblizi, or plastic clay.
C.	Light brown, argillaceous sandy earth, with scales of mica	Teane safra iblizi, yellow plastic clay.
D.	Blackish, compact, argillaceous sandy earth, with scales of mica	Teane zargha.
E.	Greenish brown, argillaceous sandy earth, with scales of mica	Teane khadra.
F.	Reddish brown, argillaceous sandy earth, with scales of mica	Teane houmra.
G.	Greyish brown, argillaceous sandy earth, with scales of mica	Teane beida.
H.	Transparent quartzose sand, rounded particles of various sizes, mixed with particles of black earth	Raml abiad, white sand.
I.	Fine, shining black sand, composed of rounded and crystalline grains of magnetic iron, with a small proportion of quartzose sand	Raml iswid, black sand.
K.	Transparent, fine-grained quartzose sand, of a light yellow tint, resembling the fine part of the sample X. Memoir, Part I. p. 130	Raml asfar, yellow sand.
L.	Very fine quartzose sand, with scales of mica	Raml azrak, bluish sand.
M.	Fine, transparent quartzose sand, composed of rounded particles	Raml Nili, clean river-sand.
N.	Gravel, composed of rounded quartz pebbles, coarse sand and angular fragments of flint	Zallat, quartz pebbles.
O.	Transparent, quartzose sand, similar to K	Raml gebeli, desert sand.
	Artificial substances.	
1.	Fragments and particles of limestone and red sandstone	Dabsh, stone fragments.
2.	Fragments of red burnt bricks	Tonb ah mar roufaiah.
3.	Fragments of pottery	Foukhhar roufaiah.
4.	Fragments of the rubbish of buildings, with lime mortar	Mouna binaiah.

The letters and figures within the sections in Plates II. and III. refer to the above Table.

The letters and figures which stand *first* in the divisions of the sections indicate the variety of the soil and of the artificial substance which predominates in the division.

* The specimens of the soils and of the objects of art found in the excavations, which are mentioned in this memoir, Parts I. and II., will be deposited in the British Museum.

HEKEKYAN BEY, in his anxiety to fulfil my instructions that every variety of the alluvial soil passed through in the pits should be noticed, carefully distinguished minute differences in composition and colour, and sent specimens of all the varieties he described. Although there are in fact only two classes, what may be termed *loams* and *sands*, I have thought it advisable to preserve in the sections HEKEKYAN BEY'S minute distinctions. I have added to the above Table the local names which he has supplied, as they may prove useful, should future geologists, directing their attention, as I trust they will do, to the same subject, chance to see this memoir.

In the sections of the borings across the valley in the parallel of Heliopolis, given in Plates IV. and V., the letters used as signs of the different soils do not indicate the same varieties as in the preceding Table; they are as follows:—

Argillaceous earthy sediments, more or less mixed with sand.

A. Yellowish brown earth.
B. Light brown, argillaceous earth.
C. Light brown, sandy earth.
D. Brown sandy earth.
E. Dark brown earth.
F. Bluish dark brown earth.
G. Reddish brown earth.

Quartzose sands.

H. Yellow desert sand.
I. Yellowish brown sand.
K. Brown sand.
L. Light grey sand.
M. Grey sand.
N. Bluish sand.

FRANKLIN INSTITUTE LIBRARY

Explanation of Plates.

PLATE II.

Sections of nineteen pits sunk in the area of Memphis, extending 2132 yards from west to east and 1576 yards from north to south, as given in the Ground Plan at page 62, showing the variations in the nature of the soils passed through at the same levels.

Pits.	Local names of the Pits, given by Hekekyan Bay.	Depths of the mouths of the Pits below the inundation level of 1851.		Distances in yards from the Pits R.	
		feet.	inches.		
R¹ R²	At the colossal statue of Metrahenny	3	6½		
No. 1.	Excavation XIII. of the section across the valley	3	6½	6 S.	25 E.
No. 2.	Excavation of Omar Effendi	2	11½	45 S.	21 W.
No. 3.	Excavation of the Palms	6	1	52 N.	24 E.
No. 4.	Excavation of the Cesareum or Serb	8	8½	260 N.	80 W.
No. 5.	Excavation of Tel Moukalid	9	10½	326 N.	151 W.
No. 6.	Excavation of the Three Colossi	5	11½	354 N.	35 E.
No. 7.	Excavation of Shimbab, No. 1	1	0½	565 S.	115 E.
No. 8.	Excavation of Shimbab, No. 2	2	1	854 S.	198 E.
No. 9.	Excavation of Shimbab, No. 3	2	1	1250 S.	291 E.
No. 10.	Excavation of Baron Erben	8	1½	40 N.	779 E.
No. 11.	Excavation of Mekias il Rod, or Nilometer* of Memphis	7	0	627 N.	758 E.
No. 12.	Excavation in the Summer Road north of the cross embankment from Metrahenny to Bedreshin, No. 1	8	3½	595 N.	875 E.
No. 13.	Excavation of Bedreshin, No. 2	5	10½	537 N.	983 E.
No. 14.	Excavation of Bedreshin, No. 3	5	1¾	491 N.	1150 E.
No. 15.	Excavation of Bedreshin, No. 4	8	0¾	490 N.	1325 E.
No. 16.	Excavation of Bedreshin, No. 5	12	7	404 N.	1470 E.
No. 17.	Excavation of Bedreshin, No. 6	15	10¼	388 N.	1690 E.

The letter F on the right of each section indicates the level of the filtration water reached in July and August 1852, except in the Pits R² and No. 6, which was in October 1854.

The letters within the sections indicate the varieties of the soils, as explained in the "Table of Soils" annexed, page 88.

The figures within the sections indicate the nature of the artificial substances contained in the soil.

The figures at the bottom of each section indicate, in feet and inches, its total depth from the surface of the ground.

* Diodorus Siculus speaks of a Niloscope constructed at Memphis by the ancient kings, divided by cubits and digits.

PLATE III.

Sections of a series of pits sunk across the Nile Valley, between the Libyan and Arabian Hills, in the parallel of the Memphis district, included within an area extending about 5 miles from west to east, and about $\frac{3}{4}$ of a mile from north to south.

Nos. 1 to 15 on the left bank, 16 to 26 on the right bank; the latter in a continuous line 490 yards south of the latitude of the excavation at the colossal statue of RAMESSES II.

Pits.	Localities of the Pits.	Depths of the mouths of the Pits below the inundation level of 1851.		Distances in yards from the excavation at the statue of RAMESSES II.	
		ft.	in.		
No. 1.	On the Montabesh* of the Western Desert	1	1	3162 W.	587 S.
No. 2.	On the Montabesh of the Western Desert	0	5	3096 W.	731 S.
No. 3.	In the Reef† of the Libyan Valley	0	$3\frac{1}{2}$	2621 W.	487 S.
No. 4.	In the Reef of the Libyan Valley	5	$7\frac{3}{4}$	2375 W.	362 S.
No. 5.	West of the Magrour or Joseph's Canal	5	1	1858 W.	210 S.
No. 6.	In the Magrour	4	10	1525 W.	220 S.
No. 7.	East of the Magrour	5	5	1375 W.	158 S.
No. 8.	In the plain west of Memphis mound district	4	6	1021 W.	81 S.
No. 9.	First pit on south side of the cross embankment on the eastern side of the mound district	6	10	1110 E.	42 N.
No. 10.	Second pit south of Metrahenny and Bedreshin cross embankment, and east of the mounds	5	$4\frac{1}{2}$	1721 E.	58 N.
No. 11.	South of the cross embankments from Bedreshin to Metrahenny.	4	8	2083 E.	69 N.
No. 12.	South of the cross embankments from Bedreshin to Metrahenny.	5	$11\frac{1}{2}$	2335 E.	80 N.
No. 13.	South of the cross embankments from Bedreshin to Metrahenny, and west of and close to the Nile dyke at Bedreshin Sahil ‡	4	9	2930 E.	100 N.
No. 14.	East of Bedreshin Nile dyke, and on the Sahil	3	4	3177 E.	100 N.
No. 15.	On the edge of the river, at its ebb on 27th May 1854	25	9	3479 E.	475 N.
No. 16.	On the western scarp of Helwan Island	19	$5\frac{1}{2}$	4254 E.	490 S.
No. 17.	On the crest of the bank of Helwan Island	3	4	4505 E.	490 S.
No. 18.	On Helwan Island	2	$10\frac{1}{2}$	4583 E.	490 S.
No. 19.	On Helwan Island	3	$9\frac{3}{4}$	4754 E.	490 S.
No. 20.	In the bed of the Anaphora§, or branch of the river between the island and the Arabian valley	7	8	5049 E.	490 S.
No. 21.	East of the Arabian dyke	6	$0\frac{1}{2}$	5240 E.	490 S.
No. 22.	In the Arabian Reef, west of Helwan Canal	3	6	5407 E.	490 S.
No. 23.	On the Montabesh of the Eastern Desert side of the valley	3	5	5563 E.	490 S.
No. 24.	On the Montabesh of the Eastern Desert side of the valley	4	$2\frac{1}{2}$	5640 E.	490 S.
No. 25.	On the Montabesh of the Eastern Desert side of the valley	4	7	5794 E.	490 S.
No. 26.	On the Montabesh of the Eastern Desert side of the valley	0	10	5923 E.	490 S.

The letter F on the right of each section indicates the level of the filtration water reached in July and August 1852, except No. 15.

The letters within the sections indicate the varieties of the soils, as explained in the "Table of Soils" annexed, page 88.

The figures at the bottom of each section indicate, in feet and inches, its total depth from the surface of the ground.

* The Montabesh is the area that is inundated but not cultivated. It is good for camels and goats, and in times of peace and confidence the poor Bedouin cultivates this land, digging pits to water it.

† The Reef is the line separating the black soil from the sandy surface.

‡ The Sahil is the space of ground left by the ebbing river between itself and its dykes.

§ HEKEKYAN BEY has applied the term Anaphora to the passage of the swollen Nile, between an island in the river and the bank.

PLATE IV.

Sections of a line of borings between the Libyan range of hills and the left bank of the Nile, in the parallel of Heliopolis, about ten miles below Cairo, described in p. 63; Nos. 24, 25 and 26 are more accurately described in page 64. The length of the line is nearly eight miles.

1. In each instance the boring terminated when the filtration water was reached, No. 1 to 23 in July, 24, 25 and 26 from September to November 1854.

2. The figures immediately below the head line indicate in feet and inches the depth of the mouth of each boring below the inundation level.

3. The figures at the bottom of each section indicate in feet and inches the total depth of the boring from the surface of the ground.

4. The letters within the sections indicate the varieties of the soils, as explained in the "Table of Soils" annexed, page 88.

Section No. 1 was 50 yards distant from the eastern slope of the Libyan Hills.

5. The figures *between* the sections indicate in yards the distances between the borings.

PLATE V.

Sections of a line of borings between the right bank of the Nile at Bessousse and the Arabian range of hills in the parallel of the Heliopolis, in a distance of about eight miles from west to east, described in page 64, except No. 1, more particularly described, page 65.

The above explanations of Plate IV., numbered 1, 2, 3, 4 and 5, apply equally to Plate V.

The section No. 2 was 629 yards from the right bank of the Nile.

No. 9 was in the summer canal of Abou-Mounedgeh.

No. 10 was to the east of the winter canal of Sharkawiyeh.

No. 11 was in a small summer canal.

No. 17 was to the east of the Cairo Canal.

No. 18 was 87 yards west of the excavation C in the Heliopolis district. (Memoir, Part I., p. 124.)

No. 20 was 166 yards west of the Obelisk of Heliopolis.

VI. *Researches on the Structure and Homology of the Reproductive Organs of the Annelids.*

By THOMAS WILLIAMS, *M.D., F.R.S., Physician to the Swansea Infirmary.*

Communicated by THOMAS BELL, *Esq., F.R.S., President of the Linnean Society, &c.*

Received December 30, 1856,—Read February 12, 1857.

ALTHOUGH several distinguished comparative anatomists have done much by their labours to elucidate the general organization of the Annelids, the reproductive system of organs in this class has been little, if at all, investigated. On this account the author of this memoir is tempted to lay before the Royal Society the results of a systematic series of researches on this subject, on which he has been, for some years, laboriously occupied. These researches conveniently arrange themselves under two leading divisions.

The first will include a merely anatomical description of the chief or typical varieties of form and structure which these organs are found to exhibit in the leading genera of the class; while the second will embrace a brief statement of such homological views as the ascertained facts with respect to their structure, form, and anatomical relations may appear to warrant.

As the organ upon which always, in some part or other of the body of the Annelid, the office of reproduction devolves, is frequently in other parts diverted to other purposes, and modified in outward characters, it will prevent circuitousness of expression if at the outset a name be adopted, under which, whatever its place, size or form, this organ may be generically distinguished.

Under the appellation of the "segmental organ*," accordingly, it is proposed to describe that viscus upon the basis of which, under several striking variations of place and figure, are always ingrafted the true generative structures. By way of a general historical introduction, the author will content himself with the following citation from the recently published lectures† of Mr. HUXLEY, exhibiting the state of knowledge on this subject at the date of its publication, July 23, 1856. "The genitalia of the typical Annelida are *excessively simple in their structure;* indeed, *special reproductive organs* can hardly

* This is an unobjectionable title; it implies no theory, it simply states the fact that the organ is repeated more or less regularly in the segments of the body. No other organ in the body of the Annelid is "segmental;" every other organ is continuous throughout the body. This is the case with the alimentary, the nervous and the vascular systems. The feet are not "organs." Indeed, so intimate in an anatomical sense is the relation between the segmental organ and the foot, that in the development of the embryo Annelid they constitute one system. The hollow bases of the feet are so frequently the depositories of the generative products, that they may be regarded as bearing the same relation to the segmental organ as the uterus does to the ovaries of the Mammal.

† Medical Times and Gazette, 1856–57.

be said to exist in most, *the generative products being merely developed* from *some part* of the walls of the perivisceral cavity into which they eventually freely float, making their way out in a manner which is not quite understood at present; probably through some temporary or permanent apertures at the bases of the parapodia."

From this passage it is obvious that by the most recent expounders of the science of comparative anatomy, it is formally asserted that in the Annelida "special reproductive organs can hardly be said to exist." It will afterwards appear that the facts to be related in this memoir conduct the anatomist to a widely different conclusion.

A brief and special historical introduction will be prefixed to each department of the subject.

By this arrangement references to the researches of other observers will be much facilitated.

The families of Annelids selected for examination will be placed in juxtaposition, more on account of an affinity of type presented by the "segmental organ" than in deference to any other principle of classification.

The Naidea, Lumbricidea, Hirudinea, Terebellidæ, Nereidæ, &c. will on this ground be taken in the order in which they are named.

Naidea.—In his Report* on the Annelids, the author made the following statement with reference to the segmental organ in the genus *Nais*: "The *whole* reproductive system is limited by Dugès to the glandular mass which is so readily observed about the anterior third of the body, whereas in reality this only constitutes *one segmental unit*, more developed only than those which are repeated in every ring of the body." Although in the present memoir the author will avail himself of the opportunity to correct certain inaccuracies committed in his "Report" with respect to the interpretation there given in relation to the segmental organ in *Nais*, he will only at present observe, that in 1852 he drew attention to the fact that the generative structures were developed upon one, two or more of the segmental organs common to almost every ring of the body.

To M. Dugès the segmental organs, as distributed throughout the two posterior thirds of the body, were unknown. No special description of them has been given by any subsequent anatomist. It is doubtful whether the genus *Nais* is included by Leydig in his recent memoir†, "Ueber den Bau und die systematische Stellung der Räderthiere," while incidentally referring to the family of the Lumbricidea. Whether this be the case or not, the author is not acquainted with any special account of this organ in this group of Annelids.

The following description is drawn entirely from his own researches:—

In the freshwater *Naides* the segmental organ is readily examined. A few individuals should be selected and placed between two slips of glass, slightly compressed, and thus viewed as transparent objects.

* Transactions of the British Association, 1852.

† Zeitschrift für Wissenschaftliche Zoologie, 1855.

Nais serpentina may be taken as the type of the genus. In this species the segmental organ is very readily studied in consequence of the softness and transparence of the integuments. Two of these organs are present in every ring of the body, one on either side of the intestine. (Fig. 1 A, B, Plate VI. indicates the system of one segment; at A the organ is shown in its perfect state, at B in outline.) Each organ (A & B) commences (or if the course of the contained current be considered, *ends*) in a single external orifice (*a*). For some distance from this attached end (to (*e*)) the organ bears a single tube, the figure being tape- or band-shaped, and the walls thick. From this point (*e*) to (*f*), a point not far from the free extremity, the band carries a double current, one tending towards and the other out from the general cavity. This is only apparent; it arises from the agglutination of two portions of the ciliated tube. If this part were examined alone, it might be concluded that the entire organ was double, bearing a double current, one going in and the other setting out from the general cavity. This apparent double current in the mid-portions of the organ proves a source of extreme perplexity to the observer. By careful observation it may be distinctly seen that both at the attached portion (*e*) and the free floating portion (*f*) the band is small and the current single. It will now be understood that the double currents, setting in opposite directions, which are seen when the middle third of the tube (*i*, *g*, *h*) is in focus, result from the folding of the tube upon itself. Insignificant as this point may seem, it involves in truth the important questions whether the segmental organ be single or double, whether it carries one current or two, whether in fact it consists of a simple siphon leading out of the general cavity, or of a complex apparatus adapted at once to excrete and to renew the chylaqueous fluid. The solution of this problem involves great care and patience.

At its free internal extremity (A, *b*), this organ is held in a determinate position by means of bridles of delicate threads fixed at (*d*). This arrangement is one of great interest, since the free open end (A, *b*) is thus held in a fixed position, one in which it can never become obstructed. By the action of the large and vigorous cilia (A, *b*), a strong current of fluid is drawn into this open mouth (see arrows, fig. 1, A). At a short distance from this extremity, which is itself trumpet-shaped, the tube undergoes a remarkably bulbous enlargement (*c*). Here the interior bore or channel is also dilated. The walls are thick and muscular, and capable of suddenly closing and again of expanding; a rhythmic movement, which no doubt is intimately connected with the power of this organ to discharge the chylaqueous fluid. This contractile property resides indeed in the parietes of the entire organ. It is a highly irritable structure. At one moment it may be seen relaxed, outstretched and floating in the cavitary fluid, at the next coiled or shrunk up into a minute ball; while in this latter state of contraction, the current of the cilia-driven fluid coursing in the interior is entirely stopped. As soon as the tube relaxes, it goes on again, and so on. Thus the normal action of the tube is dependent upon the cilia by which the bore is lined, the *irregular* action being due to an irregular contractile movement. From the form and structure of the trumpet-shaped extremity, from the setting of the ciliary currents at the mouth and at the base of the tube, it seems

beyond the possibility of doubt that the organ *in this ordinary* state subserves the function of discharging externally the fluid contained in the general cavity of the body. This fluid must necessarily escape *in body* through the tube. This organ does not appear to be endowed with any selective power over the principles or elements of which the fluid is composed. It conveys externally the entire body of the nutritive fluid, *leaving behind only the corpuscles.* This is a fact which is capable of being brought in a direct manner before the mind and under the eye of the physiologist. Around it there crowd many suggestions. It proves that in this comparatively exalted class of animals, the process of secretion, in one case at least, is accomplished by a mechanism comparatively rude, viz. by the direct, unchanged siphonic discharge (outwardly) of the body of the nutritional fluid.

The segmental organs in *Nais* cannot convey externally either the normal corpuscles of the chylaqueous fluid, or the spermatic products; these bodies are by many times too large to traverse the bores of the tubes. [But in this genus neither the ova nor the spermatozoa are at any time found in the general cavity.] They cannot convey a current of water from without to within, from the exterior into the perigastric chamber. This would be contrary, directly opposed, to the ciliary motion within the tube, which sets from within outwards.

They cannot belong, as suggested by LEYDIG, to the mechanism of the respiratory act. It is contrary to all analogy to suppose with him that they are *the* agents of the expiratory act. The inference that they are simply discharge-tubes to the chylaqueous fluid, does not necessarily imply that they are renal in office, as suggested by several authors. The preceding description applies only to the segmental organ in *Nais serpentina*, as it is distributed throughout that part of the body of the worm which is behind the reproductive mass.

In other species of this genus the same organ occurs under characters more or less modified.

In *Nais filiformis* it (fig. 2 *g*, *g*) is not so tape-like or flattened as in *N. serpentina.* The trumpet-end is differently fixed in the cavity. The tube in its mid-portion is also dissimilarly coiled. The attached end (*h*) is more muscular; the free enlarged extremity (*g*) is more elongated; but in this species, as in *N. serpentina*, the organ consists of a *single* tube, beginning internally in an expanded ciliated extremity, floating freely in the general cavity, and terminating in a thickened dilated portion, in which in an especial manner is seated a strong muscular power. In *N. proboscidea* it is formed after the pattern of that of *N. serpentina.* It is, however, more bulbous at its free extremity, and more cord-like in figure. A further variety occurs in *N. parasita.* In *N. pusulosa* (mihi) (not uncommonly found, at certain seasons, in the finest sand of the sea-shore), another modification occurs in the form and structure of this organ.

It remains now to investigate the claims of this organ in a new and hitherto unthought-of relation, namely, in that bearing in which it connects itself with the generative or reproductive structures.

It is by far the most important bearing of this subject. It has not been hinted at by any preceding observer.

In *Nais*, and, as will be afterwards shown, in *Lumbricus*, it may be readily demonstrated that one, two, or possibly more of the "segmental organs" on either side of the body undergo a remarkable increase of size and variation of form.

In *Nais* it often happens that only one of these organs on either side is thus involved (fig. 2 a, a^2; compare a, a^2 with g, g, f in the same figure). At some seasons, however (especially one in which the weather has continued for some time warm and dry), individuals of *Nais filiformis*, *N. proboscidea* and *N. serpentina* may be found in which two organs on either side have undergone a marked generative development. This was remarkably the case in *Nais filiformis* in the summers of 1850–51 *. Four organs (two on either side) were then constantly found in an enlarged and modified condition. The two anterior were developed into sacculi, in which were lodged arrow-shaped lemnisci or intromittent organs. During the present year, while conducting many hundred examinations, no single individual of the same species could be discovered in this condition. The two organs in the ring immediately in front of the genital segment have this year exhibited the ordinary or undeveloped state. It is therefore evident that only two segmental organs, the one being developed into the male and the other into the female moiety of the reproductive system, are *necessary* to the generative maturity of the individual. The anterior organs may or may not experience a special growth. When this has happened, they are accessory, not essential in office.

The two segmental organs (fig. 2 a, k and a^2, o) which form the basis of the reproductive masses (i, o), are observed even on first view to be similar in general outline to those which are repeated in every ring of the body (g; g). But on minute comparison, they will be found in reality to be identical with the latter, differing only in size and in the shape of some of their parts. The dilated portions (a, a^2) correspond in the most obvious manner with the equivalent parts (h) of the other organs. The umbrella-like extremities (k, e) (which are the same in form on the ovarian and testicular sides) are seen at once to be the counterpart of the free ciliated ends (g, g) of the ordinary organs.

* This condition is correctly represented in pl. viii. fig. 72, appended to my Report on the British Annelida[1]. I hope I may be permitted in this place to observe that, between the results of my recent and those of my former investigations on the reproductive system of the Annelids, there is no essential difference as far as the latter were carried. The following passage proves that I then suspected that the generative segmental organs were only modifications of the non-generative:—"A comparison between the familiar figures of Dugès and those which are published for the first time in connexion with this memoir, will enable the physiologist at once to perceive that the *whole* system is limited by Dugès to the glandular mass which is so readily observed about the anterior third of the body, *whereas in reality this only constitutes one segmental unit, more developed only than those which are repeated in every ring of the body*."—*Loc. cit.* p. 264. The results of my subsequent inquiries, which it is the purport of this paper to state, enable me now to contribute very materially to a better knowledge of the anatomy and physiology of this part of the Annelidan organization.

[1] Transactions of the British Association, 1851.

The latter are more pear-shaped; the former more umbrella- or fan-like. This difference of figure, it will be afterwards proved, does not involve a difference of function.

The intermediate ciliated tubes (*j*, *d*) are specially distinguished only for their great length and thickness. In all, the cilia at the free floating extremity of the organ beat in such a manner as to raise a current setting strongly *into* the organs, and out of the body of the animal. This fact is worthy of note. It proves that neither the ova nor the sperm-cells can escape through or along these ciliated tubes into the cavity of the body, supposing that in this Annelid, as in many others, they were destined at some time to find their way into this chamber. But the author has convinced himself, by recent observations, that this never takes place in this genus. The general cavity is not used at any time, or under any circumstances, for the purpose of incubation.

The ciliated tubes of the generative organs, it must therefore be inferred, fulfil the same office as those of the ordinary segmental organs; that office is undoubtedly to discharge externally the fluid of the perigastric cavity. The current thus raised, in the case of the special organs, serves also subsidiarily to convey outwards the generative products. The wider bore, more vigorous cilia, and stronger currents, are well adapted in *them* for this purpose*.

It is of great importance to place beyond dispute the mode in which the generative masses (fig. 2 *i*, *b*) occupying the special segments are related to the ciliated tubes (*j*, *d*). The first impression is that there must be some connexion between them; else why the enormous growth of the tubes in the reproductive ring, as compared with those of other parts? The demonstration of this point is attended with great difficulty. The rolling of the animal under view, and the density of the integuments, preclude a clear inspection; but it may be constantly seen that the ovarian mass (*c b*) moves to and fro *with* the dilated portion of the tube (a^2). It is impossible to *see* the opening by which the ova arrive in the interior of this part (*l*) (*utriculus*) of the tube; that they DO get there is, however, certain, for they have been actually seen therein on several occasions by the author, as shown at fig. 2 a^3. From this portion of the tube they escape by the external orifice.

It was the discovery and the clear definition of this important anatomical fact, which first convinced the author that he was justified in deducing from this arrangement the final conclusion, that *the ovarian and testicular masses in* NAIS *did not constitute detached and independent viscera, but that they were structures which were evolved from, or ingrafted upon, a segmental organ, specially modified for this purpose.*

This conclusion has been since arrived at by several different modes of observation.

The testes on the other side bear the same relation to the tube as the ovary on the side just described. The *utriculus* on the one side is represented by the ejaculatory pouch on the other. At present it is beyond the power of science to explain why these organs, in only one or two annuli of the body, should be implicated in the sexual deve-

* The corpuscles of the chylaqueous fluid in *Nais serpentina* are very large and granular: they may easily be mistaken for ova. One clear view of the *true* ova in the ovarian mass will however convince the observer that these corpuscles are not ova, but the normal form,—elements of the chylaqueous fluid.

lopment, while all the rest should remain in abeyance and in the condition of mere "excretionary tubes;" or why the ciliated tube of one side (always the same in every individual) should be changed into the female system, and that on the other into the male. Such is the nature of the *hermaphroditism* of these Annelids. It is symmetrical; the centres of the opposite sexes are separate and distinct; the organs upon which they are respectively developed are homologically identical. The vascular and nervous systems have, however, a special arrangement in each.

This centralized position of the sexual structures is peculiar to the genera *Nais* and *Lumbricus*. In every other Annelid, *Planaria* forming no exception, every segmental organ in the body is enlisted in the office of reproduction.

There is nevertheless some peculiar power resident in the ordinary segmental organs.

Towards the end of the summer these worms (*Naides*) divide themselves by fission, generally into two parts. The normal reproductive masses are always in the anterior half. The tail-half at this time *has no sexual system*; but in process of time two of the ciliated tubes will swell, enlarge in size, and at the same time become more complex in structure. It is evidently the EFFORT in the tail-half to reconstruct itself into a perfect individual. That it does become a perfect individual the author has never been able to prove by his own observations. The fact is here adduced to prove that there does reside in the segmental organ a power which enables it (the conditions being favourable) to transform itself into an ovary or a testis.

The ciliated tubes in various species of *Nais* have of late years been observed and described by several anatomists, *e. g.* by HENLE, UDEKEM, SIEBOLD, LEYDIG, GEGENBAUER and others. No one has hitherto, however, attempted to connect them with the reproductive system.

Lumbricidea.

Anatomists have long been aware of the existence of the "ciliated tubes" of the Lumbricini. By MORREN* they were described as the "Vésicules Aériennes," and as Tracheæ by WILLIS and LEO†. DUGÈS‡ states that they are "toujours remplis d'un liquide aqueux." HENLE supports this view. SIEBOLD§ professes a similar opinion. This distinguished author observes: "The structure of the respiratory system is not less difficult to be understood. In all genera (of Lumbricini) there are, at the commencement and on each side of the intestine, very tortuous canals, which open upon the ventral surface by a narrow orifice near the median line." Then, describing the cilia, he states: "In *Lumbricus* these aquiferous canals are surrounded by a very distinct vascular network, which has a botryoidal aspect from its numerous pedunculated vesicular dilatations, which are filled with blood:" and then SIEBOLD observes: "These canals, thus

* MORREN, 'De Lumbrici terrestris Hist. Nat.' p. 149.

† LEO, 'De Structura Lumbrici terrestris, dissert. inaug.' in 4to, p. 25, 1820.

‡ Consult a paper by HENLE, "Ueber Enchytræus," and 'Archiv für Anat. und Phys., von MÜLLER,' 1837, pl. 6. figs. 7, 8.

§ SIEBOLD and STANNIUS, 'Anat. of Invertebrata,' translated by BURNETT, p. 171.

situated, remind one of the trembling organs of *Rotatoria* connecting the two lateral canals with the cavity of the body." LEYDIG * has adopted and somewhat extended this homological idea of VON SIEBOLD. DE QUATREFAGES has referred to these organs under the title of "Poches sécrétices venant s'ouvrir sur le dos, &c.†" Both HENLE, SIEBOLD, and DE QUATREFAGES confess that, as yet, "*no description or figure has ever been published giving any idea of their complexity.*" GEGENBAUER‡ was the first accurately to describe the internal free, umbrella-shaped, ciliated extremity of this organ in the Earth-worm.

Thus then, in the genus *Lumbricus*, these ciliated tubes have been long known to exist; but as to their minute anatomy and their real function, nothing but confusion and contradiction have prevailed. It should be further understood, that, of the many anatomists who have more or less specially observed and studied these organs, not one has ever hinted (either directly or indirectly) at the relation in which they stand to the reproductive system. But the recent paper of HERING §, on the organs of generation in the Earth-worm, requires a special historical notice. In the course of the succeeding description it will be seen that the author differs from Herr HERING on the following important points:—1st, as to the size and position of the ovaria; 2nd, not only as to the distribution of the so-called *vasa deferentia*; but 3rd, as to the *very fact of the existence* of these ducts under any shape; and 4th, and most fundamentally, as to the connexion between the generative masses and the "segmental organs." To this latter point HERING makes no reference whatever. Lastly, the author is desirous to correct an error into which he himself was drawn while writing his "Report on the British Annelids" for the British Association (1852). By reference to that Report it will be seen that, in the worms examined in that year, the "segmental organs" in every annulus of the body were crowded with a vast multitude of the ova and young of a certain species of FILARIA. By the singular appearance thus caused, the author was induced to regard the *ordinary* segmental organs as in truth nothing but ovaries, looking upon the "central reproductive masses" as having experienced some special and distinctive development. Subsequent and most carefully-conducted researches have convinced him that he then mistook the ova and young of an Entozoon infesting the Earth-worm for those of the animal itself. He was lured into this error in consequence of regarding the *ordinary* segmental organs of the Earth-worm as the real equivalent of the ovarian segmental organ of the Hirudinæ, and not of those of NAIS. And besides, at that time the segmental organ of the Earth-worm was not known in the whole extent of its minute anatomy.

Lumbricus Jordanii‖, in the months of July and August, presents at a short distance

* "Ueber den Bau und den systematische Stellung der Räderthiere," Zeitschrift für Wiss. Zool. 1854.

† Consult pl. 21 bis, Le Règne Animal, &c. 3me grande division, &c.

‡ "Ueber die sogenannten Respirationsorgane d. Regenwurms," in SIEBOLD and KÖLLIKER's Zeitschrift, vol. iv. p. 221.

§ EWALD HERING, "Zur Anatomie und Physiologie der Generationsorgane des Regenwurms," in Zeitschrift für Wiss. Zool. 1856.

‖ This is a minute terrestrial *Lumbricus*. It is found in July and August in the fine loamy earth of gardens. It is NOT the young of the common Earth-worm.

behind, as in the common Earth-worm, a thickened ring or band around the body. It is bounded by abrupt limits, and implicates four or six of the annuli of the body. When this portion of the integument is closely examined, it proves to depend upon an extraordinary development of the cutaneous follicles. On the abdominal aspect of this thickened portion, *suctorial cups* are formed, by aid of which, during the congress of the individuals, mutual contact is maintained; but the generative segments internally *have no relation* with this suctorial ring of integument, nor has this latter part anything to do with the true *genitalia*. It is like the thumb of the Frog; it is simply a provision for the mutual apposition of two individuals. The enlarged follicles of this cutaneous ring discharge also another function; they supply that peculiar glutinous secretion which affords (in such a remarkable manner in the cases of *Lumbricus terrestris* and *L. complanatus*) a protecting capsule to the ova as they escape from the body. This peculiar hypertrophy of the integuments in the region of the reproductive segment occurs also in every species of *Nais*.

Lumbricus Jordanii is a minute worm of pure white colour. The integuments are transparent enough to enable the eye to read the interior organs. The ordinary segmental organs are present, in pairs (fig. 3 A. *m*, *m*), in every annulus of the body; they do not however float freely in the fluid of the general cavity, as in Nais. They are attached to the side of the intestine by means of threads or delicate membranes, the trumpet-shaped extremity being fixed to a determinate point.

All those organs which are distributed throughout that part which is posterior to the generative segments are in the *ordinary* condition (fig. 3 A. *m*, *m*). The internal end (*j*) of the tube in this worm is figured after a pattern intermediate between that of *Nais* and that of *Lumbricus*. It is less trumpet-shaped than the latter, and more so than the former.

In this little terrestrial Annelid, as in the aquatic Nais, only two segmental organs, one on either side, are specially evolved into the reproductive condition; in other words, only one ring of the body is implicated in this function; bearing in this respect a striking resemblance to the instance of Nais, and differing no less strikingly from that of the common Earth-worm, in which six or eight pairs of these organs experience this special enlargement. In *L. Jordanii*, as in *Nais*, the generative tubes (fig. 3 A. *a i* and a^2 *e*) are considerably developed when measured by the standard of the ordinary non-generative ones (*m*, *m*). The utricular ends (*g*, *c*) are far more elongated than in *Nais*, but they bear precisely the same relation to the ovarian masses (*b*, *b*) as is observed in the latter. The intermediate tube (*d*) is extremely coiled and elongated; the free ciliated extremity exhibits a distinctive form; it is pear-shaped (*e*, *i*); it is very long, provided with very thick walls; and at the extremity it is furnished with a lip, highly ciliated (*l*), which appears to be adapted to favour the ingress of the chylaqueous fluid into the bore of the segmental organ.

By easy manœuvres a clear sight of the reproductive masses may be obtained in all their relations. Under skilfully-regulated pressure, the entire system will burst its

boundaries and float in the neighbouring fluid. It will be observed at once that a most constant and intimate organic connexion exists between the masses (*f*, *g* and *b*, *b*) and the coiled tubes of their respective sides. The ova on the one side, and the sperm-cells on the other, may be actually seen by the eye, on many occasions, rolling to and fro in the *interior* of the dilated portions of the tubes (*a*, a^2).

To this Annelid no further reference will be necessary, since in every particular the sexual system conforms with the type of that of *Nais*. In the young of this worm the ordinary segmental organ exhibits the form shown at fig. 3, B.

It seems to the author that a candid review of the preceding facts must inevitably conduct to the conclusion that, in this species (which is evidently intermediate between *Nais* and the common Earth-worm), the ovaries on the one side and the testes on the other are not only organically connected with, but are ingrafted upon, and developed from, the standard or normal segmental organ.

In the course of his researches the author has accidentally fallen upon other species of Lumbrici, more or less favourable to the study of this question. In *L. Kanii*, mihi, in the young state, the segmental organ may frequently be discovered in a condition highly favourable to the present investigation (see fig. 4 A). In that *annulus* in which the contained ciliated tubes are destined to become the generative organs, the latter appear at first under the character represented at *c* (fig. 4 B). From one side of the mid-portion of the tube (as at *e*, 4 C) may be observed to bulge minute pear-shaped vesicles, filled with a semigelatinous fluid. Regarded as a whole, it is impossible to doubt that this organ is one of the segmental organs. If this be admitted, the conclusion cannot be resisted, that the vesicular outgrowth (*c*) is really the ovary or the testes in process of development. But in the same individual the other and ordinary segmental organs have altogether a different form and structure (fig. 4 A. *a a*, *a*, and B). Thus is adduced another well-attested fact, in confirmation of the view maintained in this paper, viz. that the reproductive organs in *Nais* and *Lumbricus* are in reality nothing but a modification of the "segmental organs" or "ciliated tubes" which exist, in pairs, in every annulus of the body.

Earth-worm.—The anatomy of the reproductive system in the Earth-worm has been made a subject of express investigation by many competent comparative anatomists.

The points in difference between the author and other observers will be indicated as we proceed.

The anatomy of this system in the Earth-worm has ever been held as almost an insoluble enigma. No intelligible clue whereby to unravel the intricate glandular mass has ever been discovered. Without such a clue the problem never can be consistently solved. It is hoped that such a clue or *principle* is afforded in the succeeding account. It rests upon the fact that between the reproductive masses and the ciliated segmental tubes there exists a *necessary* and regular connexion, and that the glandular masses of the adjacent segments are distinct from and independent of one another. A knowledge of this leading principle of arrangement enables the anatomist at once to convert a con-

fused heap of glands into an orderly system of parts, and moreover, to bring the sexual apparatus of this Annelid within the pale of definite homologies.

Every ring in the body of this worm (except a few at the head and tail) contains two segment organs, one on either side of the intestine: they are convoluted, tubular organs, arising from the ventral aspect of the general cavity near the median line, curving upwards round the intestine and terminating in a fan-shaped ciliated extremity, which is bridled to the septum near its dorsalmost edge. Those segmental organs which are situated anteriorly to the gizzard are very much larger and more distinct than those which are placed behind it.

It is desirable in the first place to obtain a clear idea of an ordinary or non-generative segmental organ in this worm. The following description is drawn from minute researches conducted with care by the author himself. Not having seen the original paper of GEGENBAUER* on this subject, he cannot say how far his own account may agree with or differ from that of this anatomist.

The season of the year, the state of the weather, have much to do with the condition in which these organs are found. All the specimens upon which the following examinations were instituted were taken in the months of July and August, from a rich, loamy, highly-cultivated garden soil.

This fact it is material to know, since nowhere, in the ordinary fields and meadows, does this worm attain the same size and plumpness. The generative *nisus* does not seem to reach its climax until the worm has arrived at a certain period of age and fulness of growth, so that, out of 100 specimens examined, only ten or fifteen may be found in that condition which is required for the successful prosecution of these researches. The accompanying illustration (fig. 5) of an *ordinary* segmental organ of an Earth-worm was constructed from dissections instituted on at least fifty individuals: so exceedingly difficult was the inquiry, that only a small fragment of this extraordinarily complex tube (extending from a to a^3, fig. 5) could be traced in each individual. It was found to be impossible to make such a section of the *annuli* as would afford a complete view of the *entire apparatus*. Notwithstanding these difficulties, the following

* *Note, added April 27th*, 1858.—I have just procured that number of the Zeitschrift für Wiss. Zool., for September 1852, which contains GEGENBAUER'S paper "Ueber die sogenannten Respirationsorgane des Regenwurms." It affords me the greatest pleasure to find that the description given in the text, and drawn exclusively from my own unaided observations, agrees almost in every minute particular with the description and figures of GEGENBAUER. It is gratifying to find one's self in agreement with so accurate an observer on so extremely difficult a point in minute anatomy. Our concord, however, ceases at this point. GEGENBAUER'S account of the complex botryoidal vascular system of the segmental organs of *Lumbricus* is little more than a passing reference. He seems neither to have deciphered its anatomy nor recognized its homological significance. He speaks of the "schleifenförmigen Organe" as intended, in function, to discharge in a direct manner the fluid of the general cavity, and also to furnish a peculiar excretion from their own walls. Although he alludes to the *increased size* presented by these organs, both in *Lumbricus* and in *Sænuris*, in the segments containing the generative masses, he overlooks completely the *organic connexion* which I have invariably found to exist between the one and the other, and upon which connexion I have attempted in this memoir to explain the homology of the reproductive system of the Annelids in general.

description conveys an exact and faithful account of the anatomical structure and disposition of this marvellous organ.

In *Lumbricus terrestris* the divisions or segments of the alimentary canal posteriorly to the gizzard and proventriculus are very numerous and closely packed. Each "ring" of the body is divided from the adjacent ones by the intervention of membranous partitions, which either completely or partially isolate the fluid contents of each annular space. It is probable, however, that the fluid of the general cavity freely oscillates from one extreme of the body to the other through perforations in the septa.

But whether the segmental spaces be isolated or not, the ciliated organs which they circumscribe are individualized and independent, the adjoining ones having no connexion whatever with one another. The following account is descriptive of all those which are situated posteriorly to the *proventriculus* and the generative region.

This organ is far more complicated in structure in the Earth-worm than it is in any other species of *Lumbricus*. The tube which connects the free extremity (fig. 5 *f*) with the fixed end (a^3) is extremely convoluted, lengthened and thickly intermixed with vessels.

This intermediate tube is divisible into three distinct portions. First, a smooth-walled, minutely diametered membranous part, which extends (from *e*, to *d*) from the umbrella-like termination (*f*) to the camerated or cellular portion (at *d*). This division of the tube is uniform throughout in diameter. It is the smallest and most contracted of the entire tube. It is vigorously ciliated in its interior bore. The ciliary current sets from the free end (*f*) in the direction of the fixed end (a^3). The next division of the tube extends from the termination of the smooth membranous part (at *d*) to the commencement of the third stage (at *i*). This portion is not ciliated. The walls bulge out into lateral cells. This part of the tube appears to split into two, which unite again, as is the case in the corresponding organ of the Rotifera. Such an arrangement is not, however, represented in the accompanying figure (5); for it is only apparent (*d*, *i*).

The segmental organ in this portion is inextricably blended and matted up with blood-vessels (although in the figure, for the sake of clearness and simplicity, the vessels are omitted). From its peculiar structure and extreme vascularity, this part may be regarded as typically indicating the true seat of the process of ovogenesis, as it occurs in the segmental organs of other Annelids.

The fourth division of the tube stretches from the end of the celled portion (*i*) to the commencement of the muscular part (*j*). This again is strongly ciliated. In function it is evidently exclusively expulsatory. Its walls are thick and contractile. The last, outermost or dilated portion (*b*), bounded internally by the smooth-walled division (*j*) and externally by the attached end (a^3), is however the most striking and remarkable part of the whole apparatus. It is almost invariably, in the months of July, August and September, crowded with the ova and the young of a certain species of Nematoid Entozoon (5, *k*), which might readily be mistaken for the ova and the young of the Earth-worm itself. Although formerly deceived by the appearance presented by these Entozoa, a

critical study of their structure has convinced the author that they are not the young of the Earth-worm, but individuals belonging to the genus *Filaria*.

This dilated muscular portion of the segmental organ is not ciliated internally. But its walls are capable of contracting vermicularly or peristaltically.

The *vascular system* connected with the segmental organ receives a special development. In *Nais*, however, this is not the case.

During the past summer, 1856, the author was so fortunate as to discover five or six specimens of Earth-worm very large, the ordinary segmental organs of which were precisely in the condition illustrated in fig. 5, in which the vascular system had acquired an extraordinary degree of development (*g g* and *h h*). The vessels connected with the ciliated tubes of the ordinary as well as with those of the generative segments were on these occasions found to be in this remarkable state. This botryoidal condition of the vessels has been cursorily alluded to by SIEBOLD and GEGENBAUER. It is not present in every individual and on all occasions. It is in some way connected with the condition of sexual maturity. That this is the case the author has assured himself by a great number of most careful dissections. Sometimes the vascular system of the segmental organ is in a state of almost entire abeyance. When present under the most evident circumstances (as in fig. 5), it may be described as consisting of three parts. First, of two or three large trunks (*n*, *g*, *m*), which curve upwards from the ventral to the dorsal trunks. These vessels form thus a *framework* by which the slender ciliated tube (a, a^2) is held vertically *in situ*, they themselves being vertically disposed.

Between the primary vertical trunks extends a vast multitude of secondary branches (*l*, *l*), which further subdivide to form a dense plexus of smaller vessels (omitted in the figure for clearness' sake), in the meshes of which the ciliated tube (a, a^2) is entangled. It is the presence of this mass of vessels which renders it so extremely difficult to trace the coils (*d*, *i*, *j*) of the tube. This reticular plexus, in a more or less pronounced form, is much more frequently present than that curious portion of the vascular system next to be examined.

As already stated, in the Earth-worm, at certain seasons and conditions of growth, a dense mass of florid blood is attracted to, and held in the region of the segmental organs. It is contained at these times, not in ordinary cylindrical vessels, but in capacious lateral cæcal branches, terminating in large bulbous pear-shaped extremities (*h*, *h*). Now this portion of the vascular apparatus of the organ evidently constitutes a *special provision*. What is its purpose? It is not fitted in any way or in any sense to aërate the contained fluid.

In virtue of a contractile power with which the bulbous extremities are endowed, not only are they adapted to attract towards, and detain in the neighbourhood of the segmental organ a large extra supply of blood, but they are also fitted to exercise a supplementary power to drive into the plexus of capillaries which more immediately embraces the coils of the ciliated tube an extraordinary supply of blood. Does not this definition at once suggest the inference, that therefore at certain seasons and under

certain conditions of growth some *extraordinary* function devolves upon the tube itself? else why this exceptional condition of the vessels? On this point the author does not at present wish to pledge himself to any particular doctrine, not even to the opinion which he ventured to express in his Report in 1851, or the opposite. All he is desirous to state is that this periodic afflux of an extraordinary quantity of blood to the region of the *ordinary* segmental organs, in the Earth-worm, seems to indicate that under the constraining influence of certain exceptional conditions they may experience a generative activity. On no occasion, however, has he been able to *prove* this by the discovery of the presence of the real ova and young of the worm itself. But in support of this view the question may be asked, if the "ordinary" segmental organ were designed merely and exclusively to drain off, in an *unselecting* mechanical manner, a given quantity in a given time, of the chylaqueous fluid, does it not seem incomprehensible that so highly organized, such a completely constructed apparatus should have been provided to execute a purpose so simple? This latter is undoubtedly its purpose in *Nais*, and accordingly the organ is reduced to the characters of a simple non-vascular tube. It cannot be the expiratory half of a respiratory apparatus, as supposed by LEYDIG; such a supposition is opposed to all that is known of the mechanism of respiration in the invertebrated animals. If it be designed to fulfil the office of an excretory gland, it may be said that by its *open* internal mouth it may eliminate, *in body* and directly, the chylaqueous fluid, while, from its peculiar connexion with the vascular system, it could only remove the contents of the latter by the normal cell-agency method of membranous secretion.

Accepted in this latter sense, they may be said to discharge a renal function. In relation to the fluid contents of the vascular system, these organs may be said to be capable of exercising a *selective* influence in virtue of some property resident in the membranous walls of the vessels and tube. But such selective property cannot be said to reside in the cilia with which the trumpet-shaped extremity of the tube is armed. They act on the cavitary fluid simply mechanically. If, therefore, the segmental organ stands in the relation of a kidney to the blood proper, it is scarcely possible that it can do so in relation to the chylaqueous fluid, unless we admit the maxim that the simpler the fluid, the simpler is the anatomical construction of the solid organs designed to react upon it.

These botryoidal appendages to the vessels of the segmental organ do not appear to exist in *Nais*, or if they do, they are so small as to be invisible even under a high power; if they do not, it is a point of difference between the structure of the part in *Nais* and *Lumbricus*.

In parting with this subject, the reader's attention is particularly drawn to the analogy which exists between the botryoidal or pear-shaped cæcal appendages which project laterally from certain of the vessels of the segmental organ of *Lumbricus* and those vascular tufts and pouches (hereafter to be described) of the segmental organs of *Arenicola*, *Terebella*, and those of the Nereid family.

The Sexual System of the Earth-worm, *Lumbricus terrestris*, appears, on a superficial inspection, to consist of an inextricably confused mass of ovaria and testes, bound to and centred in a particular region of the body without rule, law, or intelligible order*. But the results arrived at by the numerous anatomists who have laboured on this subject are still more confused and contradictory. Sir E. Home, Dugès, Meckel, Hoffmeister, De Quatrefages, D'Udekem, and lastly, and more especially and recently, Meissner and Hering, amongst many others, may be named in this category. They have bequeathed to us no consistent account of the reproductive organs of this worm. These organs have proved a puzzle to anatomists of every age; and they are so to this day, notwithstanding the meritorious researches of those whose names have been mentioned.

The author is fully impressed with the difficulties which beset the investigation. He has not therefore ventured upon conclusions with respect to the subject in dispute, without great care, caution and labour.

He now believes, however, that he has seized the true clue which will conduct the patient dissector to a complete and satisfactory solution of this long-vexed problem.

He will proceed at once to state the results of his own researches, indicating in notes the points whereon he differs from other observers.

The dissection of the Earth-worm requires great manipulative skill and experience. The animal should be pinned down (with the back upwards) to a cork-bottomed vessel. The posterior half of the body may be cut off as unnecessary for our purpose. By means of a curve-scissors a longitudinal incision should then be made along the dorsal median line. The point of the instrument should run in the hollow axis of the intestine. The integuments should then be pinned down and slightly stretched. A gentle stream of *fresh water* should now be allowed to fall on the worm thus opened. This will carry away the contents of the intestine, and float the delicate parts without arresting ciliary action. If the operation thus far has been carefully performed, the object is ready for examination. The eye should be first carefully carried along the septa, or the membranous partitions between the annular chambers. It will be seen that these membranous septa, when clearly traced out by the aid of the handle of the scalpel, divide with great regularity the reproductive masses into *segmental groups*. This point implicates a principle of great anatomical importance. It establishes this fact, viz. that the *contents* of each ring or annulus are *distinct from, and structurally independent of*, those of the adjacent rings or annuli†.

It countenances the idea of the zooidal individuality of each annulus. An annulus in the generative region is a perfect organism in its nervous, hæmal, visceral, fluid and reproductive parts, not, however, an hermaphrodite organism.

* See plate 21 bis, in the volume "Sur les Annelides," 'Règne Animal,' which is taken from the dissections of *Lumbricus trapezoides* by De Quatrefages.

† Lest the dissector who undertakes to repeat these researches should be led hastily astray, it is here proper to explain that it is meant only those parts which take their *origin* in the individual segments, not those masses which by growth swell beyond the dimensions of *several* annuli.

At this stage of the dissection, it may be easily observed that each segmental space has its own distinct and independent ciliated tube.

On further examination it will be seen that it is around the bases or attached ends of these tubes that the reproductive masses cluster.

The ovarian and testicular masses are definitely bounded by the dissepiments (*j*, *j*, *j*). The roots of these bodies are always situated within the space of its own segment; but the *body* of the larger glands (as *c* and *i*) may from their size extend across several segments.

These few leading statements explain the *principle* on which the sexual system of *Lumbricus* is constructed. (Fig. 6 represents the entire system in the condition of its greatest development.)

Before proceeding to the minute dissection of these parts, the position of the thickened collar, so prominently observed on the external surface, with respect to that of the generative masses within, should be particularly noticed. It will be seen to be placed, by several segments, behind these masses. This thickened ring is bounded by sharp borders before and behind. It involves six or eight annuli of the integuments. On its abdominal surface two suctorial cups are observable. It is most certain that these cups are not perforated at the bottom; they cannot therefore be, as supposed by some anatomists, the outlets of certain tubes within*. They are in truth designed only to hold the individual in apposition during the generative congress. That there is no organic connexion between these cups and the reproductive masses, may be further proved by carefully examining (internally) (previously dissecting away the intestine) the condition of the ciliated tubes in the intervening segments. They are not developed like those in the generative segments; they belong to the class of the "ordinary" segmental organs. These intervening annuli are not crossed in this worm, as described and figured by Hering in *Lumbricus agricola*, by the vasa deferentia and oviducts. In fact they are altogether excluded from, and beyond the limits of the reproductive segments.

Now, in studying the visceral contents of each ring within the limits of the generative region, it will be best to proceed from behind forwards.

The dissector thus comes first upon the largest and most prominent (fig. 6, *i*, *i*) of all the generative masses. They are testes. This can only be proved by the examination of the products contained within them, under the microscope. They have a white, glittering, oily colour. In figure they are intestiform, the coils, of which there are two or three, being tied together by means of a mesentery. The capsule consists of a proper membranous tunic, and is seen to be thinly supplied with vessels when carefully floated and suspended in water; these two testicular masses, which lie across and fill up several

* The distance internally between the tegumentary ring and the generative masses is represented by Ewald Hering (Zeitsch. f. W. Zool. Nov. 12, 1856) as traversed, in *Lumbricus agricola*, by the oviducts and *vasa deferentia*. The most carefully repeated dissections have convinced me that neither of these ducts exist in *Lumbricus terrestris*. If they have no existence in this species, it is highly probable that Hering has been led into error in describing them in *Lumbricus agricola*.

rings, may be traced with perfect clearness to comparatively narrow peduncles (*g*, *g*). These peduncles, when minutely and successfully dissected out, will be found to connect themselves intimately with the *roots* of the ciliated tubes or *special* "segmental organs" of the same annular spaces. If now the peduncles and the attached tubes be cut away by a curved scissors as near as possible to the abdominal surface, and then placed on a glass slide so as to admit of being examined under the microscope, it will be discovered that the tube and peduncle of the testicular mass run into one another (as shown in fig. 7 *a*, *b*, *c*) and that the outlet (*d*) is common to the peduncle (*a*) and the ciliated tube (*b*). This outlet cannot be detected on the external tegumentary surface of the animal; it is far too minute and closely contracted. No orifice can be discovered even in specimens preserved in spirits. But its position may be clearly ascertained by the position of the attached extremity, internally, of the ciliated tube. The confluence of the peduncle of the testes and base of the ciliated tube is a fact of great homological value. It proves that the generative gland is an outgrowth from, and organically the development of the "segmental organ."

It is a fact which brings the generative system of this worm, hitherto so incomprehensible, within the rule which governs the formation of this system in the Annelida in general*.

The two ciliated tubes, one on either side, which are contained in this testicular ring, differ in no respect whatever from those (fig. 5) of the non-generative rings, but in that of size. They are considerably larger than the latter, so much so as to be quite visible to the naked eye.

The botryoidal vascular appendage (fig. 5, *g g*) exhibits the same character. The tubal portion (*j e*) is only more densely coiled and complicated. The umbrella-shaped extremity is very large, and the cilia act with great force. Neither HERING, DE QUATREFAGES, nor GEGENBAUER allude anywhere in their writings to the fact, which is so significant in a homological sense, of the increased size of the ciliated tubes of the generative segments in *Lumbricus*.

Before proceeding to investigate the contents of the second (from behind forwards) generative ring, it is material that the dissector should convince himself that in the first ring nothing connected with the reproductive organs is contained but the testes and the ciliated tubes just described. No ducts crossing the space can be discovered, no ovaries or sacculi of any description.

There is therefore every reason to believe that the viscera bounded by the septa of this ring are distinct and independent, and wholly unconnected with those of the adjacent rings, and that they communicate externally by separate ducts whose openings are within the limits of this ring. This ring, then, is exclusively dedicated to the male organs. In this particular it differs from the generative annulus in *Nais*, in which the

* In the excellent paper already referred to, HERING speaks in several places of the *constant connexion* between the "schleifenförmigen Organe," ciliated tubes and the ovaries and testes. But the mere proximity, of which he speaks, is very different from the view maintained in the text.

segmental organs of opposite sides of the same ring become developed into opposite sexual parts (ovaries and testes*).

The second generative *annulus* in the order mentioned is exclusively ovarian. The greatest care should be taken to float well the delicate septa in order to define distinctly the annulus. Having done this, it will be easy to prove that the mass (f') and the base of the ciliated tube (i^2) run together, and become blended into one structure.

The most minute dissection fails in the attempt to isolate the duct which, it may be supposed, leads from the ovary. When the gland is cut out deeply in connexion with the ciliated tube, it is found to surround this tube as shown at fig. 8; so intimate is this connexion, that it is certain that (as in the case of the testes and tube in the segment behind) the gland and the tube must have a common outlet. The ovary is considerably smaller than the testes. Its capsule is more dense and vascular, and its interior structure is much more thickly supplied with blood. The vessels in the structure of the ovaries have a peculiar arrangement; they run parallel with the lobuli of the gland, a dense capillary plexus being formed between the larger trunks.

The ciliated tubes of this ovarian annulus do not differ in size or structure from those of the testicular annulus. It is therefore impossible to tell why on the one an ovary should be ingrafted, and on the other a testis†.

In the common Earth-worm the second, third and fourth generative segments (fig. 6 d, e, f) are ovarian. Each ovarian segment is anatomically only a repetition of the other; all are constructed upon the same plan. Some slight difference in the size and position of the glandular masses may be observable; there is none in their ultimate relations.

The fifth segment (from behind) of the generative rings is again testicular. In general and minute structure this segment is precisely the same as the first. At this point

* In the plate copied from his MS. and published in the grand edition of the 'Règne Animal' (vol. Annelides, pl. 21), De Quatrefages indicates the most posterior of the generative masses in *Lumbricus trapezoides* as the testes, the anterior group being the ovaries.

† Ewald Hering, in his account of the ovaries in *Lumbricus agricola*, describes and figures the ovaria as occupying the *hindmost* of the generative segments. "Durchschneidet man jetzt den Darm an der beschriebenen Stelle, so erscheinen die Ovarien unter der Loupe als zwei flache, ovale oder birnförmige, in einen mehr weniger langen Faden auslaufende Scheibchen, die an die vordere Scheidewand des dreizehnten Segments ungefähr 1 Mm. von der Mittellinie, 0. 5. Mm. von der Bauchfläche mit ihrem breiten Ende angeheftet frei in die Leibeshöhle hineinragen, so dass ihre Fläche der Bauchfläche parallel geht. Da an derselben Stelle jederseits auch das Schleifenförmige Organ befestigt ist, so isolirt man das Ovarium am besten, wenn man jenes fasst und beide nebst dem angrenzenden Theile des Septums herausschneidet. Auf einem Gläschen ist es dann leicht weiter zu isoliren. *Stets findet man den flimmernden Trichter des schleifenförmigen Organs an der Basis des Ovariums angeheftet.*" *Loc. cit.* Judging from his figures as to the real character of what Hering here describes as the ovaria, and guided by what is so perfectly and clearly demonstrable in *Lumbricus terrestris* (a species synonymous with his *Lumbricus communis*), it appears beyond doubt that this observer has mistaken some other structures for the true ovaria. Hering's account differs as widely from the statements and figures of De Quatrefages, with respect to the ovaria of an allied species, as they do from my own.

the reproductive rings terminate anteriorly, so that the first and the last segments in this region are testicular, the three intermediate ones being ovarian.

The ovaria of *Lumbricus* are much more transient in duration than the testes. The latter in a certain condition are always present at every season of the year; the former only in the summer months. The ova, while yet in the ovaria, are beautifully clear transparent cells. In August and September they seem to consist of nothing but germinal vesicles; afterwards appear the germinal SPOTS, and then the rudimentary vitellus. It is at a subsequent stage, just before their extrusion from the body, that they become covered with a cocoon or characteristic capsule, each capsule containing many ova. This capsule is a compound of chalk and *mucus*. The source of the chalk has never yet been described. In the median line between the ovaria there are situated two or more glandular bodies (fig. 6 *l*, *l*), the contents of which under the microscope prove to consist of nothing but carbonate of lime*.

Both in the ovarian and testicular segments, there are sacculi attached to the bases of the segmental organs, which in the former case serve as receptacles for the ova (*vitellaria*), and in the latter as receptacles for the semen. In one case the ova acquire their calcareous capsules; in the other the sperm-cells become developed into active spermatozoa. These membranous sacculi have long been known to anatomists. They were described in the author's Report (1854) on the Annelids, in the Transactions of the British Association.

The preceding account embodies a brief outline of the author's researches into the reproductive organs of the Annelids.

They justify the following general conclusions:—

1. That the ovaria and testes in *Lumbricus terrestris* (vel *communis*) are centralized together in one special region of the body.

2. That the ovaria and testes are situated in *different annuli* and attached to different "segmental organs."

3. That the segmental organs of the male and female annuli are identical in shape, size and structure.

4. It follows that the ducts leading from each ovary and testis, being identified respectively with the ciliated tubes of their own rings, open externally by distinct orifices. This conclusion, if true, renders it impossible that HERING's observations can be correct.

At this place it is interesting to inquire what can be the meaning of the increase of size which takes place in the ciliated tubes or "segmental organs" which are limited to the generative region, as compared with those of the ordinary segments of the body.

* The egg-capsules of *Lumbricus agricola* have been well described by Dr. GEO. MEISSNER (Zeitsch. f. Wiss. Zool. 14 Sept. 1854). He observes, "Der Regenwurm legt, wie bekannt ist, Eierkapseln. Diese sind bei den verschiedenen Arten von verschiedener Gestalt und Grösse; die Grössten sind die citronenförmigen Kapseln des *L. agricola* (vielleicht," he observes, "mit Ausnahme derjenigen des *L. gigas*, DUGÈS, die ich nicht kenne). In jeder Eierkapsel befinden sich in der Regel mehre Eier oder Dotter in einer milchweissen zähen Flüssigkeit suspendirt," &c. &c. He does not, however, allude to the chalk-secreting glands.

The first impression is, that they must be connected with the reproductive masses; but in what way and what physiological sense? It has already been demonstrated that the ovaria and testes respectively, in their several segments, are anatomically developed from the ciliated tubes. But this fact throws no light upon the use of the tubes themselves. Is it possible that they can act as the conduits by which the generative products are conveyed into the perigastric cavity? No, it is *not* possible, for the cilia by which the tubes are lined act in the reverse direction, tending rather to carry outwards, and that with great force, any body that may perchance be thrown into the channels of the tubes. This fact is sustained by another fact, viz. that in *Nais* and *Lumbricus* neither the ova nor the sperm-cells have ever, under any circumstances, been discovered in the general cavity of the body. On these and other grounds it is then probable that the augmented size of the ciliated tubes in the "generative region" may be ascribed to two causes: 1st, to the fact that they are the roots from which the ovarian and testicular masses arise; and, 2nd, that by means of their open ciliated ends, they may effect the discharge of a larger quantity of the cavitary fluid from the segments in which they are situated; and the more rapid elimination of this fluid from this region is most probably concerned in the more energetic nutrition characteristic of the generative segments*.

Hirudinei.—The segmental organ in the Leech tribe exists under very readily demonstrated conditions. Two genera of this family will be here selected for the purposes of illustration, viz. the common officinal Leech (*Sanguisuga medicinalis*), and the Sea Leech (*Albione muricata*).

The method to be observed in the dissection of these Annelids is the same with that recommended in the case of *Lumbricus*.

After pinning the *common leech* down carefully to the trough and opening the body by a longitudinal incision along the dorsal aspect, pinning down again the integuments, the whole stomach and its diverticula must be minutely picked away. The dissection should be repeatedly washed with very gentle streams of fresh cold water, in order to remove the blood which obscures everything. The object being thus carefully cleansed and then floated in water, a full and complete view of the segmental ovarian and the median testicular systems will present itself. It is most important that at this stage the anatomist should well and clearly instruct himself as to the relative extent and relative anatomical places of these two systems.

The one consists of a bilateral series, of extremely delicate floating pearly membranous organs, equalling in the number of their *pairs* that of the annuli marked on the integuments.

* In a paper in MÜLLER'S Archiv, 1844, on the genitalia of *Lumbricus terrestris*, H. MECKEL remarks that there are three pairs of testes with sacculi and three pairs of ovaries, the latter being intimately joined to the former. This statement seems to show that the results arrived at by MECKEL closely correspond with the description contained in the text. They do so only as regards the distribution of the masses of the ovaries and testes. To MECKEL, however, the existence of the ciliated tubes was unknown, nor does he suspect the importance of the septa in separating the ovaries and testes into segmental independent groups.

The other, more medianly situated, and bilateral also, consists of two series (one on either side) of spherical white little bodies, tied together by an intermediate thread, which unite at a common point anteriorly.

A third element should be noticed, namely, the small *sacculus* which, immediately behind the anterior mass of the united testes, lies also on the median line.

Now the first of these three systems of organs has been described as belonging to the reproductive system by no other writer than the author of this paper*.

By DUGÈS they have been described as the Respiratory Sacculi; by DE QUATREFAGES, in *Hirudo vacca* and other species of this genus, as the "Poches secrétrices latérales avec leur cœcum," and by LEYDIG simply (in *Nephelis*) as the analogues of the ciliated tubes of the Rotifera; by MÜLLER, MECKEL, SIEBOLD, and MILNE-EDWARDS and others, as the "internal branchiæ" or aquiferous vessels. Not one of these distinguished anatomists appears at any time to have discovered the existence of *ova* in these variously designated organs. No suspicion, therefore, as to their ovarian character, could have existed. GEGENBAUER and LEYDIG are the only physiologists who have caught even a glimpse at their true homology. Thus stands at the present time the question as to the history of the reproductive system and of the segmental organs in the genus *Hirudo*. It must be confessed that much information remains to be acquired. The author hopes that the following contribution will go far to supply this admitted desideratum.

The testes and the copulative median pouch have hitherto been regarded as constituting the entire reproductive apparatus of the Leech family. The vermiform processes appended to the fundus of the pouch have been described as the ovary, and the pouch itself as the uterus. It will now be demonstrated, for the second time, that this idea with respect to the ovarian system of this family, involves a very complete and radical error.

It may be desirable to commence by admitting, that the minute membranous organs, which in the Hirudinei exist in pairs (one on either side of the stomach) in each ring of the body, are the equivalents or homologues of the ciliated tubes or segmental organs, as already described in *Lumbricus* and *Nais*†.

* In my Report to the British Association in 1851, I described at length the anatomy of the reproductive system of the common Leech. As no reference whatever has been made to that description by any subsequent writer (see the last edition of Dr. CARPENTER'S 'Principles,' &c., Professor OWEN'S 'Lectures on the Invertebrata'), except Mr. RYMER JONES ('Animal Kingdom,' last edition, 1856), in this country, I resolved to apply myself during the past two summers to the renewed investigation of the subject. The result is that I have again and again, in every essential respect, demonstrated the correctness of my first account. Some of these demonstrations have been recently witnessed by Dr. CARPENTER and Mr. BUSK. An error or two of minute detail and of interpretation, as contained in the original report, are corrected in the improved description given in the text. In one important respect, however, the reproductive system of the Leech, although descriptively resolved, was utterly incomprehensible to me in a homological sense, for I had not then discovered that the ovaria (and their appendages) of this Annelid are really the equivalents of the ciliated tubes of *Lumbricus* and *Nais*.

† As the following passage from a recent paper by LEYDIG ("Ueber den Bau und die systematische Stel-

But notwithstanding this morphological affinity, a remarkable difference obtains between the segmental organs of the Hirudinei and those of Lumbricini, as will afterwards appear.

In Hirudo officinalis and Albione muricata *every segmental organ in the body is not only an excretionary instrument for the discharge of the cavitary fluid, but is also an ovary* *.

lung der Räderthiere," Zeitsch. f. Wiss. Zool. 1854), represents the present state of knowledge on this subject, it is here transcribed:—"Der beschriebene Respirationsapparat der Rotifera hat, vom morphologischen und histologischen Standpunkt aus angesehen, die grösste Aehnlichkeit mit jenen organen, welche bei *Lumbricinen* und *Hirudinen* als Athmungsorgane gelten. Auch bei ihnen kommen geschlängelte und genäuelte Röhren vor mit hellem Lumen, die sich entweder ohne Blase nach aussen öffnen (z. B. *Clepsine*) oder vorher in eine contractile Blase münden (z. B. *Nephelis*). Nach innen mündet der Kanal mit einer erweiterten und bewimperten Oeffnung in die Leibeshöhle aus. Ich sehe in diesem Endstück der Röhren das Analogon der 'Zitterorgane' der Räderthiere und auch die Wimperrichtung geht bei den Anneliden nach einwärts in den Kanal. Eine schöne Darstellung von der innern Mündung des Respirationskanal beim Regenwurm gibt Gegenbauer, und wie ich schon an einem andern Orte (Müller, Archiv, 1852) ausgesprochen, so bin ich der Ansicht, dass das 'arabeskenförmige Organ der *Nephelis* und das rosettenförmige Wimperorgan der *Clepsine*,' worauf auch bereits Gegenbauer angespiel that, nichts weiteres sind, als die Endstücke der Respirationskanal dieser Hirudineen. Von gleicher Bedeutung halte ich die eigenthümlichen 'pantoffel- und füllhornförmigen organe' der *Synapta digitata* welche Joh. Müller (Archiv, 1852) aufgefunden und deren feine Cilien ebenfalls nach einwärts schlagen." Leydig then proceeds to argue in favour of the *respiratory function* (!) of these organs, opposing the ideas of Gegenbauer, Bergmann and Leukart, who in *Lumbricus* attribute to the ciliated tubes the office of kidneys.

It should be here stated, that in 1852 (Annal. des Sc. Nat. t. 28. p. 175) De Quatrefages, although unacquainted with the real minute anatomy of these organs, yet hints at the analogy between those of *Lumbricus* and *Hirudo*. "Les poches latérales des Sangsues, évidemment analogues aux canaux tortueux des Lombrics, ont été considérées, soit comme des organes de respiration (Dugès et quelques autres anatomistes), soit comme des organes de secrétion devant fournir, plus particulièrement que d'autres glandes, la mucosité qui enduit le corps de l'animal. J'ai embrassé cette dernière opinion," &c.....And he embraces this opinion knowing the views which I had then published, for he observes, "M. Williams Médecin anglais, qui a publié un rapport fort étendu sur l'Anatomie des Annélides, vient d'émettre une opinion toute nouvelle. Il regarde ces poches et ces canaux comme faisant partie des *organes reproducteurs femelles* des Sangsues et des Lombrics." It will be seen that, with respect to the female system of *Lumbricus*, the results published in this paper differ in some points from those given in my Report, to which De Quatrefages alludes. My former and my recent researches differ, however, only in this particular, that whereas I formerly described every "segmental organ" in the body as an ovary, more extended study has convinced me that under normal circumstances in the *Earth-worm* only a few of these organs become developed into ovaries. In the Common Leech and the Sea-leech the *entire lateral series* of the segmental organs of the body, I still maintain, are ovarian.

It appears, therefore, that to Gegenbauer is due the merit of having first suggested the analogy between the segmental organ of *Clepsine* and *Nephelis* and that of the Earth-worm. This suggested analogy has been further extended by Leydig. By neither of these observers, however, has the slightest allusion been made to the connexion which exists between these organs and the reproductive system in these Annelids.

* I have made very numerous examinations on species of *Clepsine* and *Nephelis* which inhabit the pools of this neighbourhood (Swansea), with a view to ascertain whether the "*arabeskenförmige*" organs, as described by Leydig in these genera, contain ova in every ring of the body, as in the Common Leech and Sea-leech, or whether only a few of these organs, as in *Nais* and *Lumbricus*, experience an ovarian development, the rest remaining in the condition of mere excretionary tubes. But, in consequence of the extreme

The tube (fig. 9 *d h*, Plate VII.), which in the case of the segmental organ of the Common Leech, proceeds from one limb (*n*) of the organ and terminates in a spherical membranous vesicle (*l m*), is evidently the counterpart of the ciliated extremity of the segmental organs of *Nais* and *Lumbricus*. Both open into the cavity of the body. In the Leech, however, neither the vesicle, nor the tube into which it is prolonged, is ciliated; but, in lieu, they are highly contractile. The vesicle is the respiratory *sacculus* of DUGÈS. It does not, as DUGÈS contends, communicate externally by an orifice in the integuments, but internally with the cavity of the body as just stated. The tube which supports this vesicle arises from that limb of the segmental organ which contains the ova in the least developed condition (fig. 9 a^2. *n*, *c*). It is probable, therefore, that the chylaqueous fluid which this tube is designed to discharge, flows throughout the entire extent of the organ from the point of entrance (*n*) to that of exit (*a*), before it escapes externally. In this course the fluid may afford the materials of nourishment to the ova (in the direction of the arrows) as they travel from one limb to the other of the looped organ, and this is the more probable, as the proper tunic of the organ is very scantily supplied with blood-vessels.

The organ itself in the common leech (fig. 9) may be described as a looped tube, the limbs (*a*, a^2) of which, returning upon themselves, and one invaginating the other, open externally at the same point. These organs form two series, one on either side of the stomach. They are external to the stomach and to the testicular series. There are therefore (as in *Nais* and *Lumbricus*) two of these organs in each ring of the body. This fact is of morphological value, for the testes bear no relation either in number or position to the *annuli* of the body. The organs stand vertically *in situ*, the ends (*a*, a^2) being attached to the abdominal surface, and the *fundus* (*b*) floating upwards near the roof of the containing chamber.

FRANKLIN INSTITUTE LIBRARY.

In order to the further examination of these delicate organs they must now be cut out, as closely to the abdominal surface as possible, by means of small curved scissors. They should then be floated in water on a glass slide, covered by a thin slip and placed under the microscope. If the organs have been successfully dissected out, it will be seen that one limb (a^2) is broader and more transparent than the other (*g a*). In the former limb (a^2) the ova (*k*) are merely pellucid cells, consisting exclusively of the germinal vesicle and germinal spot. In the latter limb (*g a*) the ova (*j*) have acquired their full complement of vitellus. At this stage they exhibit a flattened ovoid form. This fact affords a demonstration as to the course taken by the ova in their passage from the ovary (*f* a^2) properly so called, towards the exterior. The seat of the true ovary is marked by the plexus of vessels (*f*). By the ovary is meant that part of the apparatus in which the ova are formed, that part which is endowed with the peculiar power of ovogenesis. In relation to this special centre, all the rest of the organ may be characterized

density of the integumenta, it was impossible to obtain such a view of the internal parts as would justify any conclusions on the subject. These organs in *Clepsina* are stated by LEYDIG to be ciliated. No cilia can be discovered in any part of their structure, either in the Common Leech or in the Sea-leech.

as the oviduct, but it is also a *vitellarium*. The tubular limb (*g a*) is entirely devoid of vessels. No part whatever of the segmental organ in the common leech is ciliated. In this particular it strikingly departs from that of *Nais* and *Lumbricus*. This observation applies also to the segmental organ of *Albione*. It is of great homological importance to note, that in *Hirudo* and *Albione* (fig. 10), and *probably* in all the genera of this family, the segmental organ is made the uterine receptacle of the ova as they are being thrown off from the ovary. *This is not the case in any other family of Annelids that the author is acquainted with, except the Aphroditaceæ and Glycera alba.* In *Nais* and *Lumbricus* the sperm- and germ-structures, as has been explained (figs. 6, 7, 8), are accumulated by the side of, or as an appendage to, this organ. In other Annelids, as will be afterwards explained, other deviations from this mode of storing the generative products occur. It follows therefore that, in the Leech tribe, the *ova* at all events at no time reach the cavity of the body. This may be one reason why in this family the perigastric cavity is so much contracted, and the contained fluid so reduced in volume.

In *Albione muricata*, several specimens of which the author has examined with great care, the female system exhibits precisely the same characters as that of the common leech. In *Albione* the *annuli* are not so close and numerous; consequently the *ovaria*, which are synonymous with the segmental organs, are not so close and numerous as they are in the common leech.

They are much larger, broader, and more evident than those of the latter Annelid.

The months of July, August, and September should be selected for the examination of this worm. When opened, after the manner already explained in the case of the common leech, the whole interior of the body, from the head to the tail, will be found to be lined by what appears to the naked eye to consist of a bright pink-coloured flocculent lining membrane. But when detached in pieces and placed under the microscrope, its real composition becomes evident.

The pink tint is due to the colour of the vitellus of the ova, and the membrane-like appearance of the whole arises from the union and apposition of the individual ova-laden segmental organs. Successfully individualized, these organs in *Albione* (fig. 10) will be found to present the same outline as those of the Leech. They are looped, horseshoe-like tubes. They are utero-ovarian as in the Leech. *Albione* differs from the Leech in two important organic facts. In *Albione* the cavity of the body is wide and spacious; in the Leech it is contracted and numerously bridled.

In *Albione* the blood vascular system is in a rudimentary stage; in the Leech it is highly developed. The ovarian limb, therefore, in the former is not vascular as in the latter.

This completes an outline of the account which the author has to offer of the *female system* of the Hirudinei:—how universal in extent and distribution, compared with that which has hitherto been received as the utero-ovarian apparatus in these Annelids!*

* In the grand edition of the *Règne Animal*, the female system in *Hirudo vacca* (see pl. 24, fig. 1, p. 213) is figured and described as consisting of a single pouch, the uterus (with its appended vagina) and two

It is noteworthy, that in the entire family of the Hirudinei the female or ovarian system preponderates considerably in size and extent of distribution over the testicular, whereas in *Nais* and *Lumbricus* the male and female moieties of the reproductive parts exhibit very nearly equal proportions. In the Hirudinei the ovaria are beyond all doubt identified with the lateral series of the segmental organs. It will be afterwards inquired how far it is correct to consider the testes as also one or more of these organs modified after a different model*. Leeches are hermaphrodite; but, although the male and female parts are present in each individual, and since there is no internal communication between these two parts, the union of two different individuals is necessary to impregnation: the individual is not fertilized by its own sperm-fluid, but by that of another.

The *male system* of the *Hirudinei* is well known to anatomists. As to its descriptive anatomy, the author has nothing now to add. He is desirous only to offer a few observations with respect to its homology.

In speaking of the ovaria it should have been stated that they are all of equal size and development. It is however a fact of singular morphological interest to note that in that particular *annulus* at which the testicular series converges, or that from which they arise, *the ovaria are wanting*. Now it is only necessary to suppose that the two segmental organs normal to this particular *annulus*, instead of obeying the rule applying to all the others, experience a special growth and expansion, giving rise, not to *ovaria*, but to highly developed and systematically distributed *testes*, and the morphologist is at once furnished with the key by which he may unlock the mysteries of this most complex and hitherto incomprehensible system of organs. In fact the two series of testicular organs, proceeding from (or converging in a penis at) one median point, represent two segmental organs, united at the mid-line and modified into this special system of parts. But all this is accomplished, not by the introduction of a new structure or

glandular appendages called ovaries. De Quatrefages thus adopts and confirms the account given many years before by Dugès of the female system of *Hirudo officinalis*. The male system in *Hirudo vacca* is correctly described by De Quatrefages. The true feminine organs he has completely overlooked. The same charge is to be preferred against this anatomist with reference to the descriptions given by him of the reproductive organs of *Hirudo branchiata* (see his "Mémoire sur le Branchellion de D'Orbigny," Annal. d. Sc. Nat. 1852). He observes: "Les organes génitaux femelles sont d'une extrême simplicité. Ils consistent *en deux longues poches renflées* en masse, dont les canaux excréteurs se renflent légèrement vers le tiers postérieur de leur trajet, et se réunissent en un seul sur la ligne médiane vers le milieu de l'intervalle qui sépare le septième et le huitième ganglion." Thus is described by De Quatrefages the female system of this leech. He here evidently mistakes the median copulative pouches for ovaria, between which and the latter there is nothing in common. In the same volume of the 'Annales de Sciences Naturelles,' De Quatrefages figures and describes the reproductive organs of *Albione muricata*. In this instance this author has not only altogether overlooked the real ovarian organs, but the true testicular series has also altogether eluded his observation!

* In my Report on the Annelids, 1851, I was led to the mistake of believing that each ovary communicates directly with each testis by means of a duct, thus permitting of an internal impregnation of the ova. This duct is however, I am now convinced, as Professor Owen (see last edition of his Lectures on the Invertebrata, 1855) has pointed out, a branch from the median vessel which goes to supply the segmental organ.

viscus, but by the skilful adaptation of a normal organ. By this simple morphological view an intelligible principle is suggested, by the light of which the most anomalous organs are reduced to a rule of consistent homology. The testes are arranged on the same plan in *Hirudo officinalis*, *H. vacca*, *H. branchiata*, and *Albione*. In all they take their origin from two segmental organs, the pair belonging to the same ring. According to this interpretation the testes of the Hirudinei are as naturally referable to the segmental organ as those of *Lumbricus* or *Nais*. In the latter the developed glands keep within the limits of the *annuli* from which they originate. In the former they extend over a considerable portion of the body. Both are traceable to the same roots.

*Terebella**.—The segmental organ in *Arenicola* will be taken as the type of the structure and function of this viscus in the family of the Terebellidæ. With these organs in the common Sand-lug every comparative anatomist, in a general sense, is familiar; on laying open the cavity of the body they appear at once under the character of vascular pouches or sacculi. By CUVIER, MILNE-EDWARDS, and every other anatomist, they have been correctly described as the true organs of reproduction. To this conclusion all have been alike driven, since no other organs in the body could be discovered to which such functions could reasonably be imputed.

This is literally all the information that we possess at the present time with respect to the generative system of this and the allied genera of Annelids.

It may well be asked how far does this information carry the philosophic anatomist? It is in truth of little value. It conveys no homological idea. It implies no general principle. It does not connect the reproductive system of this genus with that of any other Annelid. It establishes no system.

It cannot be disputed that organs so important as the generative, must in the very nature of things be subjected to the governance of a morphological law of more or less extended application. Abrupt transitions and exceptions are impossible.

There is no difficulty in proving that the reproductive system of *Arenicola* is a direct continuation of that which has already been described in the Lumbricidæ, Naidæ, and Hirudinei. The morphologist thus rises, step by step, accumulating proof upon proof of the *unity* of the segmental organ in the several families of Annelids as they are being successively examined.

In *Arenicola piscatorum* (common Sand-lug) there are six lateral pouches which, in healthy specimens, during the months of July and August are in a condition of extreme vascularity. They are quite visible to the naked eye, by their bright red colour. The minute structure of these pouches can be studied by carefully dissecting them from their attachments to the abdominal wall of the cavity and placing them under the microscope.

* Under this head the genus *Arenicola* is included, on the ground of the close anatomical resemblance which exists between its segmental organs and those of *Terebella*. The former is classified as a Dorsibranchiate, and the latter as a Cephalobranchiate Annelid, terms apparently descriptive of wide differences. Beneath this exterior difference there lie however the strongest proofs of intimate relationship of structure in some of the most important organs of the body.

One of them thus viewed is shown at fig. 11. It consists of a simple sac, or bag, the distal fundus of which (*c*) is cæcal. The interior cavity (*m*) throughout the upper three-fourths, from *d* to *c*, is a single undivided space. The attached extremity is formed into two very distinctly marked channels or tubes (A *b*), the interior of which is lined by cilia which beat in opposite directions. In the glandular tube (*a* A) the ciliary current sets towards the cavity of the organ (*m*); in the simple tube (*b* B) it sets out from this cavity (as indicated by the arrows). Although this organ has long been known to anatomists, this peculiar looped formation has never been recognized. The lining membrane is everywhere covered by ciliated epithelium. In the fundus the current leads up on one side, and down towards the outgoing limb on the other. The two limbs (A *b*) by which the organ is tied to the wall of the perigastric chamber are not similarly formed. The ingoing limb exhibits a more glandular character; its walls are considerably thicker and more richly supplied with blood than those of the other. About the middle of its course it enlarges into a round gland-like body (*l*), the axis of which is perforated by the tube. This gland is subdivided into parallel lobuli, the vessels being specially and peculiarly distributed. It is therefore not a simple bulging of the tubular leg of the organ. It is a special structure, destined to perform a special office, which will be afterwards explained. The exact mode and the place, in which this ingoing limb of the organ begins, is a point of essential importance to determine. As long as the author's investigations were confined to full-grown specimens, necessitating the part to be cut out in order to be examined, he found it impossible to solve this point. It was only after having discovered young *Arenicolæ* in a suitable condition, that he was enabled to prove by direct demonstration that it commenced in an *external* orifice (A^b) on the abdominal surface of the animal. If this limb opened directly into the general cavity, it would be the exact equivalent of the ciliated trumpet-shaped extremity of the segmental organ of *Nais* and *Lumbricus*. The ciliary current in this limb (A^b, A) would then consist of the cavitary fluid; but as this limb opens externally, the ingoing current which it serves to convey can consist only of sea-water.

It is of great interest to inquire, What can be the purpose of this inflowing stream of the exterior sea-water? Is it intended to replenish the fluid contained in the cavity of the body? If so, this organ in *Arenicola* performs an office which is precisely the reverse of that which devolves upon it in *Nais* and *Lumbricus*. But it is certain that the fluid thus introduced into the cavity of the organ (*m*) is driven out again, in whole or in great part, by outwardly-acting cilia through the limb (*b* B). That this second or outgoing tube *also opens externally* (B^b), can be distinctly seen by the eye (in young specimens properly arranged for the examination). The water-current, therefore, which is driven into the organ at the limb (A), is driven out again almost entirely at the limb (B): none, if any part at all, penetrates into the cavity of the body. Now there is no doubt upon the author's mind, although he has never been able actually to demonstrate the fact, that this outgoing leg (*b*) of the looped organ (A, B) not only communicates directly with the exterior, as at B^b, but also, by means of a

lateral process (*n*), *opens into the cavity of the body*. It is by this last process that the ova in the female and the sperm-cells in the male reach the perigastric chamber. As far as the commencement of this lateral process, the generative products are conveyed by the cilia-excited water-current already explained; but how they are made at this particular point to turn towards *n*, the opening leading into the perigastric chamber, instead of escaping externally with the water-stream through B, can only be explained by ascribing to this spot a vital sphincteric selective office. The only link that is wanting in the chain of evidence proving that the ova *are formed in* and then pass out from the segmental organ into the perigastric chamber, is just the opening from the former into the latter. The ova in the female and the sperm-cells in the male are abundantly and constantly found in the fluid of the general cavity, and the author has repeatedly, in the series of observations which he has instituted upon this subject, actually seen, in large crowds, the *ova* in the outgoing limb (*b* B). The ova at this point consist of clean pellucid germinal vesicles. The vitellus has not yet appeared. After they have sojourned for some time in the general cavity, the latter begins to show itself. Now although the author, in consequence of the peculiar difficulties of the subject, has never been able to demonstrate clearly the mode by which the generative products pass from the segmental organs into the perigastric cavity, he is compelled to believe that this passage is made, from *the fact* that the ova, at one stage, are actually seen *in the segmental organ*, at another, *in the general cavity of the body*. To complete the chain of evidence it is only necessary to *demonstrate the mode* in which they escape from the one place into the other. The segmental organ is the true ovary in the female and the true testes in the male. It is not difficult to prove this proposition. The ingoing limb of the organ (as far as the point *d*) is a highly *glandular* structure; its vessels are densely packed and specially arranged; its walls are thick and stromatous; at its mid-point (*l*) is a noted glandular development. From the vascular system of this gland proceeds the great vascular organ stretching from g^2 to g^1.

To the one side of this great vascular system there are appended peculiar cæcal pouches (*e e*); from the other (*f f*), a dense capillary plexus. This vascular appendage is the morphological equivalent of the blood-system connected with the ovogenetic limb of the segmental organ of the Leech (*f*, fig. 9), and of the botryoidal apparatus of vessels (*h h*, fig. 5) connected with the segmental organ of *Lumbricus*.

It is impossible that this most singular system of vessels can discharge any other function than the following: viz. (*a*) it is the receptacle of an extra supply of blood to an organ susceptible of periodical expansion; (*b*) it excretes something from the blood-proper into the cavity of the segmental organ (*m*), which is essential to the further development of the generative products. In *Arenicola* it is quite certain that the ova and sperm-cells pass through the last stage of their development in the perigastric chamber. How they escape out of this chamber has never yet been proved *.

* Rathke and Grube have argued that *Arenicola* is androgynous. De Quatrefages, however, from his knowledge of the development of the spermatic particles, has long recognized the existence of separate

It now remains to show that the segmental organ of *Arenicola*, the minute anatomy of which has been just described, is the homologue of the segmental organ of *Nais*, *Lumbricus* and *Hirudo*.

If the partition (*d*, fig. 11) which separates the two rudimentary limbs (A, B) of this organ were carried a little higher in the direction of the fundus (*c*), the entire organ would be converted into *a tube*, which, if one end of it opened into the cavity of the body, instead of communicating externally, would correspond precisely with the *ciliated* tubes of *Nais* and *Lumbricus*. But sufficient of the tubular character is presented by the structure of this organ to connect it indisputably with its homologues in *Nais*, *Lumbricus* and *Hirudo*. In all it is a *looped* organ; in all it is the basis of the reproductive system; in all there passes through its axis a current of fluid, the design of which is to transport the generative products, either into the cavity of the body or externally. The difference is only in the mode in which the tube is folded upon itself.

It is here of importance to remark that this is the *first Annelid* we have encountered, in which the cavity of the body has been employed as a receptacle for the generative products. The segmental organ being still the true generative apparatus, a change of anatomical arrangement became obviously necessary, in order to adapt it to the novel condition just stated.

Terebella.—The segmental organ in the genus *Terebella* (fig. 12) occurs under a form and character which ally it in the most direct and intimate manner with that of *Arenicola*. *T. nebulosa* is an elegant Annelid. It is large enough to admit of dissection. In the summer months the blood-vascular system is highly developed, the branchiæ are brightly florid, and the segmental organs (when the worm is opened) present an intensely vascular appearance.

Dissected in the usual mode, removing with care the alimentary canal, it will be seen that a series of curved elongated sacculi (of which fig. 12 are two specimens) exist on either side of the ventral median line. They extend throughout the setiferous portion of the body (in this family it may be called the thoracic), and seem to be as numerous as the largest setiferous feet, which in *T. nebulosa* are sixteen in number.

Although the identity of the segmental organ of *Terebella* and that of *Arenicola* is so evident as to admit of no doubt, yet there are between them several differential features.

In *Terebella* the organ is more deeply divided by the partition (fig. 12 A. *j k*) between the limbs than it is in *Arenicola*, a fact which approximates it more nearly to *a tube*.

The vascular appendage (*h*, B) is also differently placed. In *Terebella* it is in con-

sexes in *Arenicola* and *Terebella* (Comptes Rendus, xvi. 1843); but long before this, STANNIUS had concluded that the sexes were separate in *Arenicola*, from the fact that in different individuals the contents of the general cavity of the body were different (MÜLLER, Archiv, 1840). STANNIUS also observes that the parent sperm-cells leave the segmental organ (his testes) before the formation of the spermatozoa, which are found only *in the cavity of the body*. KROHN, in *Alciopa*, confirms this fact (WIEGMANN'S Archiv, 1845). Put the great mistake committed by KROHN, FREY and LEUCKART is, that they assert that in *Arenicola*, *Alciopa*, *Nereis*, *Syllis*, *Sabella* and other Annelids, the *ova* and the spermatozoa "*are developed free in the general cavity* . . .!!"

nexion with the ingoing limb, in *Arenicola* with the body of the organ. This circumstance with still greater emphasis points to the ingoing limb (*f m*, B) as the seat of the ovogenesis; indeed the entire dark half of the organ (*m f*) may be correctly called an ovary. The limbs of this organ in *Terebella* have precisely the same anatomical relations as in *Arenicola*. The ingoing leg (*f m*, B) (*f f j*, A) commences in an *external* orifice (*d* B, *c* A), and therefore carries *water*, as in *Arenicola*. This water traverses the organ as indicated by the arrows at A, fig. 12.

The outgoing limb (*k c*, A) is formed after the model of the corresponding part in *Arenicola*. The main channel opens externally (at *c*). A secondary tubular process (*e*) leads into the general cavity; it serves to convey into the latter the ova or sperm-cells, as they are conducted to this spot by the ciliary epithelium which lines the interior of the organ (A).

It will be seen that one half (*f m*, B, fig. 12) of the segmental organ in *Terebella* is highly vascular and glandular, and that the other half (*n n*, B) is simply excretory and membranous. This distinction marks also the offices of these halves respectively. The peculiarly evolved vascular system is connected only with the ovarian or spermatic half, the other half being simply the oviduct or *vas deferens*, according to the sex.

In the male and female *Terebella* the segmental organs are precisely the same in number, size and structure. It is only possible to distinguish the sex by the microscopic examination of the morphotic elements contained in the segmental organs and in the general cavity of the body. In the female they are ova, in the male they are sperm-cells, or spermatozoa in both situations.

The general cavity in *Terebella*, as in *Arenicola*, acts as a reservoir in which the generative products complete the last stage of their development. In the female it is a *vitellarium*, in the male a *vesicula seminalis*.

The segmental organs in *Terebella* differ in number in different species; in none do they differ in minute structure. In *T. nebulosa* this organ is segmentally repeated sixteen times; in *T. conchilegia* only six times (in other words, it is only present, in pairs, in six segments); in *T. multisetosa* twenty-four times; in *T. cirrata* about eighteen times; in *T. parvula* only three times. In all it is constructed on the type of that of *Arenicola*.

Between the genus *Terebella* and that of *Arenicola*, as regards the reproductive system, there prevails *apparently* one striking difference. In the former the anatomist discovers a large glandular mass, extending from the head along the median line to some distance in the direction of the tail. This gland-structure coincides internally with the smooth, foot-like, dense tegumentary structure observable in every species of *Terebella* on the thoracic half of the abdominal aspect of the body externally.

It has been described, by Cuvier, Milne-Edwards, De Quatrefages, Grube, Stannius and others, as the testes.

At one time the author of this paper also put upon these parts a similar construction; he has however since convinced himself that they have nothing to do with the system of the testes, nor do they aid in any way in the process of reproduction.

They are present alike in the male and in the female. In structure they consist of follicles filled with large fatty particles, differing most widely from the true sperm-cells. The office of this median glandular mass is undoubtedly to supply the lubricating and cementing fluid by which the animal forms and moulds its tube.

The testes in the male *Terebella* are the lateral pouches or true segmental organs, as in the female they are ovaria. In this genus, as in *Arenicola*, the generative products in both sexes are early introduced into the general cavity, in the fluid of which they rapidly become developed.

In concluding his remarks upon the Terebellidæ, the author is anxious to recapitulate one or two points. That the lateral pouches are the real reproductive organs is certain from these facts:—

At a particular season they are crowded with ova (in the female) and sperm-cells (in the male). These products respectively are less developed than those contained in the general cavity; but as to their being one and the same bodies in the two places, there is no doubt. Next, there is the negative evidence of the absence of any other organ in the body entitled to be called a genital apparatus. And thirdly, there is the incontrovertible proof, derived from the structure and segmental position of the organ, that it is the homologue of that part in the Hirudinei in which the ova are formed and afterwards lodged throughout the entire period of their intra-maternal life. The segmental organ of the Terebellidæ, as will be afterwards proved, bears a most intimate analogy to that of the Sipunculidæ amongst the Echinoderms.

Sabellidæ and *Serpulidæ*.—The system of the segmental organs in these families presents several peculiarities. In the true Terebellidæ these organs were found to be restricted to the thoracic or anterior portion of the body. In the genera *Sabella* and *Serpula* the case is reversed; they are absent in the thoracic and present only in the abdominal portion. They are far more numerously repeated in these families than in the Terebellidæ. As formerly stated, the ova and sperm-cells in the latter escape into and float freely in the general cavity of the body. This is not the case in *Serpula* and *Sabella*. Although the generative elements escape out of the channel of the organ (fig. 13, *a d b*) (probably at *c*), they do not pass into the free space of the perigastric chamber, there to float about, as in *Arenicola* and *Terebella*. They are bounded by a delicate membrane or bag (as represented in the case of *Chloræma*, fig. 23 *e e e*), the cavity of which is intersected by vessels and areolar tissue, and filled with a glutinous fluid, quite unlike the chylaqueous fluid, by which the ova are fixed and tied together, generally into rows. To what part of the ciliated tube (*a d b*, fig. 13) in *Sabella* it is attached, it is impossible to determine with exactness; but that it is not the ovary, but only a receptacle for the ova, will be afterwards shown to be highly probable, from the conditions under which it occurs in *Chloræma* and some Nereids.

In *Sabella* and *Serpula* the organ is the same in figure and structure. It is a looped tube (fig. 13), the fundus of which (*d*) is dilated, as compared with the two limbs; with one, the ingoing limb, is connected a dense tuft of looped vessels (*f*, *g*, *e*). The interior is highly ciliated.

In every species of *Sabella* and *Serpula* examined by the author, the sexes have been seated on separate individuals. In the majority of species the ova (*h*) have a bright pink colour. The female, by this mark, may be readily distinguished from the male, the colour of which is brownish or greenish*. From these statements it follows that the segmental organ in *Sabella* and *Serpula* are *permanent viscera*, and not temporary formations, as affirmed by De Quatrefages. In fact, it is a mistake to suppose that the process of ova- and sperm-development, *in any Annelid*, is limited to a month or two in the year. Ova in an immature state are found in the bodies of the youngest as of the oldest. This fact proves that the structures by which the ova are generated must be permanently present.

The preceding account of the segmental organs of the Sabellidæ and Serpulidæ has been drawn from an examination of the following species:—*S. alveolata*, *S. vesiculosa*, *Leucodore ciliatus* (very favourable for this purpose), *Amphitrite auricoma*, *Sabella à sang vert*, *Sabella hospita* (mihi). Of the Serpulidæ the author has only studied with care the following species:—*S. triquetra*, *S. contortuplicata*, *S. lactea*. In all the Sabellidæ and Serpulidæ the segmental organ is present in every ring of the body, except the thorax and the caudal appendage.

The Nereid group.—Under the head of the Nereid group, for the purposes of this memoir, several families of "errant Annelids" will be included. Of the reproductive organs of this group nothing whatever is known. No comparative anatomist has even suspected the existence of the "segmental organ" in any one of the members. Stannius, Kölliker and De Quatrefages, and probably other microscopic observers, have indeed established the fact that the ova and the spermatozoa are found on separate individuals. Hence has been inferred the diœcious character of this group. Not one single observation has ever been made by any of these observers as to the character of the reproductive organs themselves. The author begs therefore to offer the succeeding description as drawn exclusively from his own researches.

In every Nereid, the ciliated, looped, horseshoe organ to which the author has applied the name of the "segmental organ," exists without a single exception.

The demonstration of this organ in *Nereis margaritacea* is attended by great difficulty. It can only be accomplished either by the tedious process of placing annular *sections* of the body under the microscope, or by the discovery of a young specimen at that age at which the integuments are transparent; and then it is only in the region of the tail of the worm that the ciliated organ becomes visible to the eye. In *N. margaritacea* it

* Stannius and De Quatrefages have already pointed out the fact that the sexes were seated on separate individuals in the *Sabellidæ*; but it is evident from the following passage, that De Quatrefages has altogether overlooked the real ovaria and testes of these Annelids, and mistaken for them the masses, attached to them, of the ova and sperm-cells. He says in his essay, "Sur les Hermelliens" (Ann. d. Sc. Nat. 1848, t. 10, p. 46): "Le testicule consiste en une sorte de trame aréolaire d'une ténuité extrême, qui part de l'aponévrose médiane," &c.... "L'ovaire est en tout semblable au testicule." De Quatrefages then states that these organs are temporary, and, after the ova and the sperm-cells pass into the general cavity, they disappear through atrophy. It will be seen how entirely the results stated in the text differ from those published by the French naturalist.

consists of a tube, highly ciliated, both ends of which communicate with the *exterior*. The ingoing limbs (fig. 14, *d d*) are situated in the immediate neighbourhood of each dorsal foot. The outgoing limbs (*b b*), considerably longer and more tubular than the former, open externally to the median side of the root of each ventral foot. The cilia by which this horseshoe tube is lined are highly vigorous, capable of supporting a powerful current. Thus much is quite certain*, that this current arises externally and terminates externally. It can consist, therefore, only of the exterior element. The current of the element thus excited can only traverse the organ itself. It cannot enter into the perigastric chamber. But it can, as will now be shown, convey outwards the generative products along the outgoing limb. And this, as evidence accumulates, will appear as the true function of this water-current.

With the short, broad, ingoing limb is intimately connected the tuft of cæcal vessels (*e e*, fig. 14) to which, in other Annelids, reference has already so often been made. Now if the demonstration could be pushed no further than this point, it would confessedly be difficult to connect this horseshoe ciliated tube, and its associated tuft of vessels, with the true reproductive function. But it is capable of proof that the ova in the female, and the sperm-cells in the male, escape, although in some undetermined mode and by some undemonstrated passage, from this organ into the complexly areolated tissue (shown at fig. 15 *e i a g*) which fills the chamber of the pedal appendages. From various observations the author is persuaded that this tissue is *a development from the segmental organ* (at fig. 16, a single cirrus filled with this ovarian tissue (*d*) and its blood-vessels is figured), and that in size and vascularity it is proportionate to the stage at which the contained germinal elements have arrived†.

In the Nereid group generally the female is much larger than the male. This difference is very striking in *N. lamelligera* and *N. renalis*. The cephalic extremity of these worms is entirely destitute of the "segmental organ." This is also remarkably the case in *Nephthys Hombergii*. The nervous chord in this œsophageal region is highly developed in all the Nereid group.

This feature of structure is also very prominent in the Ariciadæ‡. The segmental organ in this family is limited in its distribution to the two posterior thirds of the body. The ova- and sperm-bearing masses (fig. 17 *a h c* and *a h c*) exhibit the same relation

* In *Spio vulgaris* and *S. coniocephala* I have enjoyed the advantage of demonstrating this fact to Mr. Busk and Dr. Carpenter.

† Until I came to study the generative system of the Annelids, I always looked upon the florid and brightly vascular elements of the feet as specially designed to fulfil a *respiratory function*. I am now convinced that, if this purpose is fulfilled at all, it is only so incidentally. The great and paramount office of these specially developed parts of the vascular system is to supply the means of growth to the generative organ. It is now almost certain that what Milne-Edwards has called the "branchial hearts," in the Eunicidæ, are sacculated developments of the vessels designed to supply the reproductive system.

‡ The drawings which accompanied the original draught of the present paper to the Royal Society, included carefully executed figures of four species of *Aricia*, viz. *A. Cuvieri*, *A. Owenii* (mihi), *Janira crinigera* (mihi), and *Janira illecta* (mihi).

to the ciliated tube as that which has already been explained in the Sabellidæ and *Nereis*.

These Annelids present a favourable opportunity for determining the question whether the large masses (fig. 17 *a c* and *a c*) of ova which in the female *apparently* occupy the perigastric chamber, are really IN that cavity, or are contained in the areolæ of a delicate stromatous tissue as already described in *Nereis*, *Sabella* and *Serpula*. Well-defined and repeatedly conducted observations have convinced the author that the latter, and not the former, is the case. In the Ariciadæ especially, it may be observed that the peculiarly areolated tissue in which the ova are contained is distinguishable into two parts, one of which is densely and intimately connected with the blood-vessels (see fig. 16; fig. 17 *c h*), the other forming a mere utricular receptacle to the generative elements (fig. 17 *a*, *a*; fig. 15 *e*). There is no doubt that that portion (fig. 17 *c h*; fig. 16 *d b*) which is ultimately bound up with the vascular system, is designed to supply a fluid secretion, *from the blood-proper*, which is necessary to the further growth of the generative products. This illustration confirms what has been constantly observed during the foregoing descriptions, that the blood-proper system in the Annelids is much more intimately connected with the process and the organs of reproduction than the chylaqueous fluid. This important fact implies evidently a difference of vital and chemical composition in these two fluids. The higher fluid is used for a higher purpose, the lower for a lower. The segmental organs in the Ariciadæ occupy the floor of each annular compartment (as shown in fig. 17 *i j* and *i j*).

The genus *Nerine*, first defined by Dr. JOHNSON, affords by far the most favourable conditions for the study of the segmental and reproductive systems of any of the Nereid families. The coast near Swansea is inhabited by three species of this genus (viz. *N. vulgaris*, *N. comocephala*, *N. beata* (mihi). The last, and unfortunately the rarest, is beyond comparison the best adapted for the purposes of the present investigations. In this elegant worm the entire apparatus (as represented in fig. 18 *a b c* and *a b c*) may be readily and clearly defined by the eye. It is here quite easy to demonstrate the connexion between the ciliated tube (fig. 19 *a b*) and *the appended mass* (*c c c*) of the germinal products. This mass fills completely the hollow bases of the foot and the entire chamber of its own segment. *It embraces* the ciliated tube (*a b*). It is evidently a part of the latter; and yet in the most transparent specimen (*Nerine beata*, mihi) it is utterly impossible to define how the germ-products escape from the tube (*a b*) into the mass (*c c c*). But the author is most anxious to draw especial attention to the fact of the presence of this ovarian or sperm-mass (according to the sex) in constant and visible association with the ciliated looped tube. It serves to reflect light upon the association of the same parts in specimens in which the demonstration is necessarily obscure. It illustrates *the principle* contended for in this paper, that the "segmental organ" is the true and real source of the generative products; in other words, that the latter are THE organs of reproduction; the masses appended to the latter, hitherto mistaken by DE QUATREFAGES for ovaria and testes, themselves being only the utricular or spermatic receptacles of their products.

There is no discoverable difference between the segmental organ of *Nerine* and that of *Nereis*. The ova are very distinctive and characteristic, however, in the former.

The segmental organs are very largely developed in the genus *Eunice*. The blood-vascular system is here highly developed. The branchiæ, which carry the blood-proper exclusively, are closely connected with these organs. The same trunks supply the cæcal tufts of the latter and the straight capillaries of the former. All the Euniceadæ are diœcious. The female is nearly twice as large as the male during the height of the reproductive season. Although they *appear* to be in the free cavity of the body, it is quite certain that the generative products do not move to and fro in the fluid of that cavity. They are contained in a delicate areolar structure, which serves to limit the products of each segment to its own proper chamber. The ciliated tube and its appended vascular tuft (fig. 20 *c*) can only be demonstrated by transverse vertical sections of the body; sometimes, and by a pure accident, a most complete view of the segmental organ (*a e b*) may be obtained by this method. It is a far more saccular and prominent organ in *Eunice* than in *Nereis* and *Nerine*. The fundus (*e*) shows a union of the two limbs as in *Terebella* and *Arenicola*, and as in the latter, the vascular, ovarian or ingoing leg is of a denser structure and darker colour than the outgoing limb (fig. 20 *a*), which is long and tubular*. There is every reason to believe that in the allied genera of *Lycidice*, *Aglaura* and *Œnone*, the segmental organs coincide in structural type with the standard of that of *Eunice*. They are, however, less vascular than in the latter. All the genera of this family are diœcious.

In the genus *Syllis* the segmental organ, which cannot by any manœuvre be directly demonstrated, is most probably correctly represented in its minute and general anatomy by that of *Psamathe* FUSCA, a closely allied genus. Once recognized in this Annelid, there is no difficulty in readily demonstrating the entire characters of the segmental organs. The integuments covering the roots of the feet are perfectly transparent. Within the hollow of each foot a beautifully looped, extremely delicate, slender, membranous, ciliated tube (fig. 21, *a b c*) may be discerned, corresponding in every essential particular with the looped ciliated tube of *Nerine*.

But what is of special interest in this case is, that the appended glandular yellowish mass (*e e*) in the female, which spreads irregularly into the hollow bases of the cirri and setiferous feet, can be most distinctly traced into organic connexion with the ciliated tube, and with that limb (*a*) of the loop, of which the vessels are most developed. During the constant movement of the little worm while under examination, it may be distinctly observed that the ova- or sperm-bearing mass *moves in constant connexion with the ciliated tube*. So exquisitely delicate is the entire apparatus, and so minute are the ova, that it is quite impracticable to trace them in their passage from the "mass" into the tube. Since however this fact has been observed, beyond doubt, in other Annelids, and since it is supported by the analogy of everything that is now clearly known with

* The dissections upon which rest the statements in the text, were made upon *Eunice gallica* (MILNE-EDWARDS), *E. sanguinea*, and *E. Harrassii* (M.-E.), which are common on the shores around Swansea.

respect to the reproductive organs of the Annelids in general, the conclusion may safely be drawn, that in escaping from the body the ova take the course of one of the limbs of the ciliated tube*.

Cirrhatulus Lamarckii is a common worm on the coast of the Bristol Channel. It may be readily found in every stage of growth. The region of the tail, in some specimens, at a certain (young) age is quite transparent. It is then easy to obtain a view of the segmental organ (fig. 22 *a c b*). In this worm, as in the Nereids generally, the *ova* are not retained within the segmental organ as in the Leech tribe; they escape into a dependent tissue which fills the chamber of the annulus in the mature individual. It is provided with its own specially disposed vascular apparatus (*d*). Its position in the chamber of the segment is vertical. The ends of the loop are situated closely together. In general figure the organ is intermediate between that of *Terebella* and that of *Nerine*. The sexes in *Cirrhatulus* are situated on separate individuals.

The author has made numerous attempts to arrive at a correct knowledge of the segmental organ in *Glycera alba*, an Annelid which is remarkable for the entire absence of the blood-vascular system. He has been able to do little more, in consequence of the dense character of the tegumentary structures, than to prove the presence of the organ. It has been observed by De Quatrefages, but never anatomically defined. It is an irregularly looped organ, destitute of a vascular tuft, and *unciliated*. In another particular it is remarkable: the ova in the female are retained within the proper limits of the membranous walls of the organ itself, after the type of the ovarian segmental organs of the Hirudinei. This fact the author has proved repeatedly by direct observation; but it may also be established negatively. The branchiæ are capacious hollow processes, communicating in the most open manner with the perigastric cavity. The fluid of the latter circulates freely in the former. In this branchial fluid the ova are never observed.

In looking back over the preceding description of the segmental organs of the Nereid group, it is impossible to resist the belief that, notwithstanding the numerous varieties of size, figure, position, structural peculiarities, mode of the looping of the ciliated tube, the place and method by which it is connected with the mass of the generative products, and other diversities, in one and all the genera, it is beyond all doubt *the same organ*. If the identity of the organ in the several groups of this family be admitted, then the homology between the Nereid type of the segmental organ and that of the other families of Annelids already referred to in this memoir, must also be admitted. This conclusion is one of great importance and novel interest. It simplifies a question which, up to this moment, has proved as complex and perplexing as any problem in comparative anatomy. It affirms that hitherto, and in the typical families of Annelids examined, the anatomist has discovered only *one essential organ*, under manifold varieties of form, upon which is ingrafted the reproductive system.

* By reference to a paper by De Quatrefages in the Annales des Sciences Nat. 1854, on the development of the spermatozoids in *Thrrea vitrea*, it will be seen that in no single particular are the results of my researches on the genus *Syllis* confirmatory of the statements which he has made.

Let us now proceed to trace the segmental organ throughout other and still more remarkable variations of type, preserving nevertheless its homological identity.

De Quatrefages has devoted a separate memoir* to the publication of the results of his researches into the organization of the family of the Chloræmea (of Dujardin). His investigations seem to have been most elaborate, and yet De Quatrefages has been entirely misled in reference to the reproductive system of this family. He thus expresses himself:—"Je n'ai rien vu dans les Chlorèmes qui pût être regardé comme un organe reproducteur, ce qui tient sans doute à l'époque de mes observations, qui, par deux fois, ont eu lieu en automne. Toutefois je ne puis croire encore avec M. Costa que les sexes soient réunis, soit chez les Chlorèmes, soit chez un genre quelconque de cette famille. Les organes que ce naturaliste à regardés comme des testicules occupent exactement la même position que les glandes salivaires que j'ai décrites, et sont représentés par l'auteur lui-même comme tenant à l'œsophage. De nouvelles observations bien précises me paraîtraient donc nécessaires. Dans le cas où le fait annoncé par M. Costa viendrait à être confirmé, il en résulterait que les Chlorémiens devraient entrer dans le groupe des Annelés dioïques où ils représenteraient les Annelides tubicoles, comme les Lombrics et les Naïs représentent les Annelides errantes."—*Loc. cit.* This is all that occurs in the special memoir of the French anatomist with respect to the reproductive system; such an account can hardly be said to be either consistent or intelligible. But De Quatrefages himself admits that new observations, *bien précises*, on this subject are necessary. The author of this memoir hopes that this desideratum will now be supplied.

FRANKLIN INSTITUTE LIBRARY.

Chloræma Dujardinii is very frequently met with on the Welsh coast of the Bristol Channel. If the principle be conceded that the segmental organ, with its associated germinal masses, of this Annelid, may be received as expressive of a law applicable to the entire class, points of clear morphological meaning will now be placed beyond the possibility of controversy. In order to verify by observation the facts now to be narrated, it is necessary that specimens in a suitable condition should be examined at two different seasons, viz. in May and June, and in August and September. In the individuals examined during the former months, the fact will most certainly and easily be established, that the ova in the female, and the sperm-cells in the male, are most clearly and distinctly contained *within* the membranous limits of the segmental organ†. In those observed later in the season (August and September), the state of things delineated in fig. 23, Plate VIII., will almost constantly be noted; viz. that in which the ovules and sperm-cells have escaped from the segmental organ and accumulated in large irregular masses (A *e e e*, female) (B *d d*, male), which float in the fluid of the general cavity, but which are bounded by a distinctly limiting membrane. This membrane it is which prevents the germinal products from entering directly into the free space of the perigastric chamber; and observation proves that at no stage of their development do

* Ann. d. Sc. Nat. tom. xii. 1849.

† Amongst the original drawings which accompanied this paper to the Royal Society, were two illustrating the conditions referred to in the text.

they enter into this chamber. In this particular the Chloræmea fall in with the rule which prevails without exception throughout the great group of the Errant Annelides. Recognizing the parallel tubes (A *b* and *ff*, and B *b*) as the true segmental organs, and remembering the demonstrated facts, that at one time the germinal products are actually to be seen within these tubes, and that at another they hang in masses externally around them, the truth of the proposition contended for in this memoir is established, that the segmental organs are in the female the true ovaria, and in the male the true testes. But careful homological study is required, in order to convince one's self that the primary and secondary looped tubes of the Chloræmea are in truth the morphological representatives of the ciliated segmental tubes of the Nereid families. In the Chloræmea these tubes are *not* ciliated, either within or without. This is a distinctive peculiarity, which allies them with those of the Hirudinei. But they stand alone and without example amongst the other Annelids in this feature, viz. that the *three* looped organs (*ffc*, A) on either side are connected together by means of intermediate tubes. The anatomical conditions in the male (B) and the female (A) are precisely the same. The same description applies to both.

The worm being properly arranged for observation under the microscope, it may be seen that at the base of the cephalic tentacle, on either side, there appear the ends of two independent tubes (fig. 23, *a*, *b*). The smaller one (*a*) is invaginated or embraced by the larger (*b*). The smaller is very much darker (in the female) in colour than the larger. This colour is due to the vitellus of the ova. The larger one is pellucid and colourless, and filled (in May and June) with ova in a very immature condition. By this distinction of colour the entire organ may be traced backwards in the direction of the tail of the animal. At a short distance is discernible a second bulge (*c*) in the transparent half of the tube. From the centre of this bulge or dilated portion there proceeds a secondary tube (*f*), which, forming a short loop (*j*), returns upon itself, and ends by a similar tube in the longitudinal tube (*a a*). The second lateral loop is formed in the same manner. The third and the last (*c a*) is formed by the union of the two long ducts (*b c* and *a a*). The limbs (*f*, *f*) of the secondary processes have at the points of their origin (*c*, *c*) an external communication, but the returning or dark-coloured limbs, which end in the horizontal duct (*i a*), have no such external communication. They open outwardly only at the extreme cephalic termination (*a*); all the loops, however, by some means or other, are enabled to discharge their contents into the appended masses (*e*, *e*, *e*), which correspond with the former in number and position.

Now if the connecting tubes (*k*, *k*) which unite the secondary loops (*fj*, *fj*) did not exist, the analogy between the latter and the normal or standard segmental organ of the Nereid group would be at once admitted; but the presence of intermediate ducts, which unite all the secondary parts into one system, involves apparently the morphology of the chloræmacean organ in difficulty and doubt, and withdraws it from the chain of that series which, up to this point in the class, has been found to consist of links uninterruptedly connected and reciprocally related.

This doubt arises from a superficial and not from a real dissimilarity. Each loop is evidently a correct representative of a segmental organ. In *Chloræma Dujardinii* (fig. 23) there are only three of these loops; in two new species* discovered by the author they amount to four and six. The Chloræmea are allied to the Terebellidæ in this particular, that the segmental organ is limited to a few of the thoracic segments. It is absent in the abdominal. The Chloræmea resemble the Nereids and Sabellidæ in this respect, that neither the ova nor the sperm-cells, at any time, are introduced into the free cavity of the body. No special expansion of the blood-vascular system occurs in connexion with the apparatus of the segmental organs. The blood in every species is green.

The *Nemertine Annelids* were described some years ago by De Quatrefages, as presenting a singular anomaly in the structure and disposition of the generative system. In the genera *Lineus*, *Borlasia* and *Nemertes* he gave an elaborate account of the alimentary organ, which in these genera so prominently occupies the axis of the body, under the title of the "ovarium." In his "Report on the Annelids," in 1851, the author contended, in the strongest terms, that the ovarium of De Quatrefages was in truth "a great alimentary cæcum;" observing that "at short distances, along the whole line of the body, on either side of the great 'cæcum,' membranous sacculi existed in the intervals between the lateral pouches of the alimentary tube, *on which sacculi undoubtedly* the office of reproduction devolved." This description has recently, in all its details, been adopted by an English writer on Natural History, without one word of acknowledgment.

The following statement is based upon observations far more extensive, numerous and *skilled*, than those upon which the original "Report" of the author rested. Examined by itself, and without the guiding ideas suggested by the preceding history, it would have been quite impossible to have unriddled the mystery of the reproductive or segmental system of the Nemertidæ. So slippery, and dense, and untransparent are the integuments, so completely does the great alimentary cæcum fill up the "cavity of the body," and so intimate and frequent are the connective bridles between its lateral cæca and the integuments, that no original demonstration of any value could have been arrived at. Having seized the clue, and knowing what to look for, the demonstration of the true segmental organs becomes certain and easy.

They correspond in number, not with the cæca of the alimentary canal, but with the *annuli* of the body. The marks of these *annuli* are not written on the exterior tegumentary surface; they are distinguished only by the transverse septa which internally cross the cavitary space at regular intervals and parcel it into segmental chambers. In each of these chambers are lodged two segmental organs, one on either side of the median line. In the female they contain ova; in the male, sperm-cells. There is only one species amongst the numerous members of this family in which it is possible to *demonstrate* the segmental organs *in situ* and as transparent objects under the microscope, viz. in *Polia quadrioculata*; it is a semitransparent flesh-coloured worm. Sometimes, by a

* Drawings of which were forwarded to the Royal Society with the original MS. memoir.

happy accident, individual specimens are met with, in which the *ova*-bearing segmental organs can be most clearly and distinctly seen. In the other genera of the Nemertidæ dissection is necessary.

The segmental organs of the Nemertidæ coincide in shape, place and structure with the *ovarian* or *female series* of the Hirudinei in these respects. In the female they are utriculo-ovarian, they retain within their own limits the ova, they observe the Annelidan type of the horseshoe or looped figure, and they are co-numerous with the true segments of the body.

The male system, in every respect, is the precise correlate of the female. There is no analogy between the *male* organs of the Nemertidæ and those of the Hirudinei. In the latter a special segment is devoted to the male apparatus, and the individuals are hermaphrodite; in the former, the sexes are seated on separate individuals; the entire series of segmental organs in each sex respectively being converted into ovaria and testes. As the vascular system is little developed, it sends no special branches to the segmental organs.

The discovery of the real generative parts in the Nemertidæ enables the naturalist to determine their true affinities in the class. It is evident that to place them under a common title of Turbellaria in contact with the Planariea, is to ignore altogether the existence of the organs of reproduction, for in this respect they are separated from the Planariea by a very wide interval. The latter are monœcious, the former diœcious. Nor is there the slightest analogy in the plan of structure upon which the alimentary system is formed.

These two groups are joined together by only one common character, and that the most superficial, namely, by the ciliated integuments. The author proposes, therefore, to separate the Nemertina or the cestoid Annelids from the true Turbellaria, synonymous with the order Planariea, under which order he includes only the tribes *Cryptocœla*, *Dendrocœla* and *Rhabdocœla*. These latter are united by a striking similarity of structure; all are hermaphrodite, in all the reproductive organs are formed on one common type.

Although the organization of the Planariea has long been known to anatomists, there remain to be noticed several points of morphological novelty. No attempt has ever been made to connect the generative viscera of this family with those of the typical Annelids. In the characters of these organs, the Planariea, on a superficial view, appear to be irreconcilably separated from all the normal Annelids. A deeper insight into the homology of these parts will, however, most certainly enable the philosophic anatomist to recognize in them none other than a modification of the typical segmental organ which, under many variations of outward form, has now been traced almost throughout the entire class of the Annelida.

The generative organs of the Planariea consist *apparently* of two parts, viz. of a central male sacculus (fig. 25, *b*) with its dependent cæca, and of a central female sacculus (*c*) with its complex system of appended canals (*d d* and *f f*). Thus it seems that

the universal rule which requires that the segmental organs should observe a bilateral and symmetrical arrangement in all Annelids, is entirely set aside in this case. This anomaly will be found, however, rather to corroborate than to violate this morphological principle.

The male system (*b*) is in truth composed of two distinct segmental organs, fused into one sacculus in the median line. The female system (*e*) is also composed of two distinct segmental organs, blended like the male into one vagino-utricular pouch in the median line.

This simple view of the case resolves all difficulties. If the *four* constituent organs stood apart from each other and in their normal anatomical positions, they would at once be seen in their true morphological relations. But these relations are not the less real, albeit they are rendered the less obvious by the fusion of the two opposite organs.

The testes (*e e*, fig. 25) are two long unbranched cæcal appendages; the ovaria (*d d*, *f f*) constitute a widely-distributed and complexly-branched system of cæcally-ending canals, all meeting at the utricular centre (*c*). No part, either of the male or female system, is ciliated. The ova are at all times contained within the limits of the tubuli (B); they never fall into the general cavity of the body. In this particular the segmental organs of the Planariea agree with those of the Hirudinei and Aphroditaceæ. It should here be noted as remarkable, that this is the first occasion on which the anatomist has observed a *branched structure* in the segmental organ. It foreshadows that formation which will be immediately described in the corresponding organs of the Aphroditaceæ. The looped or horseshoe-like character is now surrendered. But although this type of structure is lost, *the homological identity of the organ itself is unquestionably preserved.* Thus far, then, the history of the reproductive system of the Annelida has proved to rest on a natural and consecutive series of individual demonstrations, following one another in an order of obvious and necessary sequence.

We now approach the last link in the Annelidan chain. It surpasses all the others in interest; it enables the morphologist to state that the exception proves the rule; it is hoped that it will bring within known analogies systems of organs which hitherto have been regarded as irreconcilable anomalies. This remark could scarcely until now have been made with reference to the segmental organs of that class, of which, indeed, *nothing whatever* was known.

The author is not aware that any light whatever has been thrown, by any former anatomist, upon the nature and structure of the generative and segmental system of the Aphroditaceæ.

When he commenced his researches on this subject, he had to grope through perfect darkness. He could draw no light from anterior investigations; no anatomist had ever before recognized the generative organs of this family under any shape. The problem to be solved, therefore, was not simply to *discover* the true organs upon which the function of reproduction devolved, but, being known, to bring them within the sphere of established homologies.

The family of the Aphroditadæ comprehends the genera *Aphrodita*, *Polynoe*, *Pholoe*, *Sigalion* and *Spinther* (JOHNST.).

They are all more or less common on the coast of the Bristol Channel. In all, the system of the segmental organs is reducible to one typical standard. The sexes are seated on separate individuals.

The anatomical position of the segmental organs involves questions, the morphological meaning of which (as will subsequently be discussed) extends far beyond the limits of this family of Annelids.

Let us take for type the condition of these organs as they exist in *Aphrodita aculeata*. In order to arrive at a correct estimate of the reproductive system of this Annelid, specimens of both sexes should be examined in the spring, and again in the autumn. A good example of a female Aphrodita being obtained, the dissection should thus be proceeded with:—Pin the animal down to the trough with the back upwards. Open it by a longitudinal incision extending from the tail to the head. The incision should cut through the scales, felt and integuments, in order to lay open the spacious perigastric chamber. The integuments should be now carefully stretched and pinned down to the sides. The interior is now exposed. Let the dissection be then gently floated in salt water. The entire alimentary system and a considerable portion of the segmental system will be now rendered perfectly and distinctly recognizable. At this stage the parts will present exactly the appearance exhibited in fig. 26, in which a network of minute tubes or threads (*d d*, *b b*, *c*) seem to twine around and embrace the diverticula (*a*, *a*, *a*) of the alimentary canal *. From the gastric end of the proboscidiform œsophagus (*e*, fig. 26) to the tail, the digestive cæca (*a*, *a*) are co-numerous with the feet, into the hollow bases of which they are inserted.

In proceeding to the second stage of this dissection, the entire alimentary system must be taken away, and with it, necessarily, a considerable portion of the reproductive network. If this part of the proceeding be delicately and successfully performed, a perfect view will have been obtained of the attached ends (*a*, *b*, *a*, *b*, fig. 28) or roots of the branched segmental organs (A, B). These roots will be found to equal the alimentary cæca in number, and therefore that of the feet which are situated posteriorly to the proboscidiform œsophagus. They appear under the character of pyriform tubuli (*a*, A, *a*, B), commencing or ending in a single external orifice (*a*, *a*). Internally they are lined by a ciliated epithelium, the cilia being large, dense, and acting with great force and vigour. The current raised by these cilia sets up on one side and down on the other (see arrows). The ciliary epithelium ceases at the point where the primary branches (*b*, *b*) divide. All the rest of the organ (from *b* to *c*) is *unciliated*, and filled with the reproductive products. This portion is elaborately branched (at A *d* is shown a small portion, magnified, of the female organ, at B *d*, of the male),—the branches, as formerly stated, twining round the diverticula of the stomach. No microscopic object can

* Both the number of the alimentary diverticula and that of the embracing segmental organs have been very much reduced, for the sake of distinctness, in this figure.

be more beautiful than a portion of this tubular network (taken from the female organ). The individual tubes are bridled (A *e*) on one side, and glandular (A *d*) on the other. A similar structure is exhibited by the male tubes (B *d*).

The author thinks it probable that if the roots or attached ends (*a*, *a*, fig. 28) of these organs could only be followed through the integuments to their extreme outlets, they would be found to divide into two limbs, an ingoing and an outgoing; a fact which would account for the clearly divided ciliary currents, as they are seen in the dilated portions (A, B) of the organs (see arrows). If this fact of the bifurcation of the tube were clearly determined, there would be no difficulty whatever in connecting the segmental organs of *Aphrodita* with their homologues in the typical Annelids. In the absence of *proof* upon this point, however, they must be described as commencing in a *single tube*, the internal extremity of which divides into a numerous system of branches. None of these branches communicate openly with the general cavity of the body. It is therefore probable that these organs are exclusively dedicated to the office of reproduction. They seem unfitted to discharge any subsidiary function.

Now there are several features in the history of the segmental system of *Aphrodita*, which irresistibly suggest certain definite inferences as to its morphology. In the first place, the individual organs are segmentally or annularly repeated; in the second, they constitute a symmetrical bilateral series. They arise from either side of the median ventral line. They float in the fluid of the perigastric cavity (accidentally tangled around the gastric cæca). The ova in the female, and the sperm-cells in the male, are seen with perfect clearness *in the interior* of their branching tubuli. The significance of these facts cannot for a moment be disputed. If there be any basis of truth or fact in the science of comparative anatomy whereon to rest the doctrine of equivalent forms (morphology), it cannot be denied that the branched segmental organs of *Aphrodita* are only another example, under the guise of an unusual variation, of the typical segmental organ as now described in the Annelids in general.

In *Sigalion*, *Pholoe* and *Polynoe*, this system occurs under precisely the same characters as those just indicated in *Aphrodita*. If there be any difference, it is marked only by the number and complexness of the branches (fig. 27 A, B).

The blood-vascular system in all the Aphroditadæ is almost, if not entirely wanting; upon this special point the author has instituted numerous and careful observations. In no instance whatever amongst this family has he ever succeeded in detecting the faintest trace of a blood-vascular system, except in *Pholoe inornata*. In this little Aphrodite a vessel may be seen, carrying a colourless fluid, in contact with and parallel to the ventral nervous chord, slowly undulating with pulsations. Practically this fluid-system is wanting in the Aphroditadæ; it can therefore play no part in the generative functions. As will be subsequently shown, this fact, added to a mass of others, will compel the morphologist to admit a close zoological affinity between the aberrant Annelids and the Asteriadea and Echinidea among the Echinoderms.

This completes the anatomical history and morphological relations of the segmental system of organs in the class Annelida.

It now remains to speak of the leading points thus established. The demonstration has been long and difficult. The general results are satisfactory in the highest degree. It may be convenient to condense them into the shape of a few recapitulatory statements.

1. In the Lumbricina (including the Naides) only a few of the segmental organs are concerned in the office of reproduction. The others are diverted to a subsidiary purpose, viz. to eliminate the chylaqueous fluid. This may *possibly* be the case in *Clepsina* and *Nephelis*.

2. In the Hirudinei the great majority are dedicated to the development of the feminine or ovario-utricular system, and only two, or four (according to the species), to the male apparatus. It is not yet clearly proved whether in this family the collateral function of discharging the cavitary fluid is or is not accomplished by this organ. The Hirudinei, the Lumbricina, and Planaridæ amongst the Annelids are hermaphrodite. No other Annelid falls under this designation.

3. In the Terebellidæ and Arenicolidæ, the segmental organs are definite in number, but bearing no reference in their number, although in position, either to the segments of the body or to the branchiæ. They communicate with the cavity of the body, which stands to the ova in the relation of a vitellarium. This is the *only group* in the entire class of Annelids in which the perigastric chamber is made a place of sojourn for the reproductive elements.

4. At the Sabellidæ and Serpulidæ commences the Nereid type. The segmental organ becomes now a simple looped vascular tube, *both ends* of which open externally, and through the interior of which is driven, by ciliary force, a current of the *external element* (water), and to which is affixed a gland-like appendage, in which in the female the ova, in the male the sperm-cells, are retained after these products escape from the true testes and ovaria.

5. This description applies in every sense to the segmental and reproductive system of the entire Nereid group. In this and the former division every segmental organ in the body, both in the male and female, is engaged in the reproductive function. There are no non-generative organs as in the Lumbricinæ. The distinctive characteristic of this and the former group is that the generative products, although *formed* in the segmental organs, are not retained in them, nor are ushered into the perigastric cavity. They sojourn in appended pouches as already defined.

6. This definition applies also to the Chloræmea.

7. The segmental organs of the Nemertidæ or Cestoid Annelids conform in structure with the type of the lateral ovarian pouches of the Hirudinei, differing from the latter in having the sexes on separate individuals.

8. In the Planariea the type of the organ changes. There are only four original

segmental organs, which are now fused into two. The external orifice is single, and the organ is branched and unciliated.

9. In the Aphroditadæ the segmental organ forms a bilateral series, each organ having a single orifice and branched, the sexes being separate.

Homology of the Segmental and Reproductive Organs of the Annelida.

The history of this system of organs has now been traced uninterruptedly throughout every important division of the class of Annelids. Its continuity as an organic system within these limits has, the author trusts, been fully and completely demonstrated. But the homological relations of this system do not terminate at the limits which define the Annelids proper into an independent class; they are traceable with clearness and certainty into other and apparently very differently organized classes of animals. They will serve to connect together large groups of inferior forms between which, as hitherto believed, no zoological affinity existed. In this sense the inquiry into the morphological relations of the segmental organs of the Annelids assumes a character of unusual importance. A few detached conjectures upon this subject some years ago were thrown out by LEYDIG:—"Das 'arabeskenförmige Organ' der Nephelis und das 'rosettenförmige Wimperorgan' der Clepsine, worauf auch bereits Gegenbauer angespielt hat, nichts weiteres sind, als die Endstücke der Respirationskanäle dieser Hirudineen. Von gleicher Bedeutung halte ich die eigenthümlichen 'pantoffel- und füllhornförmigen Organe' der Synapta digitata, welche JOH. MÜLLER (Archiv für Anat. u. Physiol. 1852), aufgefunden und deren feine Cilien ebenfalls nach einwärts schlagen*."

In a very recent paper "über Hydatina Senta†," LEYDIG speaks of the ciliated tubes as "Respirationsorgane."

From these passages it is evident that this comparison between the ciliated organs of *Clepsina* and *Nephelis* and those of *Synapta digitata*, was suggested to the mind of LEYDIG simply by the fact, that in each instance the organ terminated internally by an expanded ciliated umbrella-like extremity. His comparison ends where this arbitrary and unimportant point of resemblance ceases. He originates no morphological principle. The resemblance which he suggests is a mere accidental observation.

The author will now proceed to develope the views, with the importance of which he is deeply impressed, which he has been inductively led to adopt from a clear and convincing recognition of an *essential unity of design* in the structure and uses of the segmental system of organs throughout the classes to which his observations relate. The subject may be conveniently distributed under the following arrangement of heads:—

* Zeitsch. f. W. Zool. 1854.

† MÜLLER, Archiv f. Anat. u. Phys., 1857.

FRANK INSTITUTE LIBRARY

The segmental organs of the	Are immediately homologous with those of the
Lumbricina Naidea	Hydrozoa Actinozoa } Cœlenterata. Rotifera.
Hirudinei Clepsina Nephelis	Synaptiadæ. Holothuriadæ.
Terebellidæ Arenicolidæ	Sipunculidæ. Echiuridæ.
Nereidæ Chloræmea	
Planariea	Trematoda.
Aphroditadæ	Echinadæ. Asteriadæ.

The author has drawn up the above table of homologies from an extensive and careful series of dissections and practical comparisons. He is deeply imbued with the conviction, that the parallelism which it purports to sketch will acquire greater and greater importance as special anatomical investigations extend.

If the generative system of *Lucernaria* be compared with that of *Actinia*, a close and striking resemblance in structure and disposition will be at once perceived, notwithstanding that in *Lucernaria* the organ is branched and multiplied by lateral cæcal tubuli, hitherto undescribed. In both there is a coiled ciliated tube; in both there is an appended mass of ova or sperm-cells, according to the sex. So intimate is the similarity of form between the complex tubuli which are attached to the mesenteric septa in *Actinia*, and the ciliated or segmental organs of the Lumbricina, that the idea of their typical identity at once arises in the mind. If it be conceded that these two forms are the homologues of each other, it follows that the ciliated tubes of *Lumbricus* and *Nais* are in truth the homologues of the radiated reproductive system of *Lucernaria*, and, through this zoophyte, of that of the entire group of the Hydrozoa*. And this conclusion (startling as it may now appear), as minute anatomy proceeds in her course of discovery, will certainly come to be universally admitted.

The mode in which the ovarian and sperm-masses are connected with the convoluted chords in the generative organs of *Actinia*, affords a strong proof in favour of the view

* The segmental organ in the hydroid polypes sinks into a condition of rudimentary abeyance. But that they do exist along the lines which indicate the positions of the vertical septa of the higher grades of polypes, I am persuaded. The time will come when it will be necessary to review the entire doctrine of generation in connexion with the system of the segmental organs. My observations have strongly suggested to my mind the belief that the gemmæ in the hydroid polypes only arise along those vertical lines of the body of the parent, beneath which there lie *rudimentary* segmental organs, and that the *gemma* most probably proceeds from an *ovum*, and not from any indifferent portion of the parent-structure.

which the author has given as to the relation in which the great ovarian and testicular masses in *Nais* and *Lumbricus* stand to the ciliated tubes.

If the author's interpretation with reference to the reproductive system in these two genera be founded in truth, then it must follow, of absolute necessity, that the reproductive masses in the Rotifera bear to the "trumpet-ending ciliated tubes" an exactly similar relation.

This inference however, thus forcibly pressed upon the morphologist, is directly contradicted by one of the most recent writers on natural history, who declares most emphatically that the ciliated tubes of the Rotifera, which, like those of *Lumbricus*, *Nais* and the Hirudinei, open by trumpet-shaped extremities into the perigastric chamber, "have nothing whatever to do with the generative organs*!" LEYDIG has already suggested a form-likeness between the "arabeskenförmige Organ der Nephelis" and the "rosettenförmige Wimperorgan der Clepsine," and the "Respirationsorgan" (as called by him) of the Rotifera. With the most unfeigned respect for this sincere and straightforward naturalist, the author is compelled to observe that he has only understood one-half of this great homological question. The form-likeness does not end with the ciliated tubes. It extends to the *function*, to the associated germinal masses: though in both the tubes are excretion organs, they are something more and deeper.

The "füllhornförmige Wimperorgane am Gekröse hängend" (MÜLLER) of *Synapta digitata*, have already been compared by LEYDIG to the "arabeskenförmige Organ" of *Nephelis*, and to the "rosettenförmige Wimperorgan" of *Clepsina*. But this comparison involves only one-half of the truth. If there be any probability in the view maintained in this memoir, the ciliated organs of *Synapta* are themselves only modifications of the cæca or tubules, upon which the office of reproduction devolves, being *ovaria* in the female and testes in the male.

Both are equally homologous with the typical organ.

At present it would merit the censure of being speculative, if an attempt were made to interpret the "respiratory tree" of *Holothuria* and *its* generative system. It is not improbable that, when *correctly described*, they will legitimately fall within the definition of the segmental system as propounded in this memoir. This Echinoderm is so rare however in the British seas, that conjecture as to the nature and character of its segmental system must for the present be postponed.

The form which the segmental organ exhibits in the Terebellidæ and Arenicolidæ, meets with an exact counterpart in that of the Sipunculidæ and Echinidæ. In the Sipunculan Echinoderms there is no *ciliated* organ. Those which are present are engaged in the generative function. They are simple cæcal pouches. They fail in their resemblance to their homologues in the Arenicolidæ in this respect, that at their attached extremities they are not divided into two limbs or tubular processes as in the

* This is all that I am willing to say in this place; but I trust, in my forthcoming Report on the Annelids, in the Transactions of the British Association, to enter at much greater length into the important and interesting history of the "segmental organ."

latter. As far as it is possible at present to determine, however, they have only a single external opening. But it is certain there exists between their tubular interior and the perigastric cavity some *open communication*, since the ova and sperm-cells find a path from the former place into the latter.

The segmental organ of the Nereid group must be looked upon as only a variation from the type of that of the Terebellidæ and Arenicolidæ.

So obvious is the unity of type between the segmental system of the Planariea and that of the Trematoda, that no controversy can for a moment be thought of.

The segmental system of organs in the Aphroditadæ is now first demonstrated. Neither its nature nor its homologue has ever before been brought within the reach of demonstration.

But so unquestionable is the morphological resemblance between it and the reproductive organs of the Echinidæ and Asteriadæ, that it is impossible to doubt their morphological affinity. They agree in two points of structure: both have a *single* external orifice or attachment; both are cæcally branched. And it may be added, that in all, the germinal products are retained within the proper membranous limits of these organs in all these families; at no time do they escape into the general cavity of the body.

Thus, through the morphological relations of the "segmental organ," not only are the orders and genera of the Annelids themselves linked into one consistent chain of reciprocal relationships, but a new point of comparison, a new bond of teleological affinity has been discovered between great divisions of annuloid and radiated animals which hitherto have been held as irreconcilably separated.

Swansea, October 1857.

Explanation of the Plates.

PLATE VI.

Fig. 1. A, B, a pair of the "ordinary" segmental organs of *Nais serpentina*; A *a*, the attached extremity opening externally, the arrow shows the direction of the ciliary current; *b*, the trumpet-shaped ciliated internal extremity, which floats freely in the fluid of the general cavity of the body. The current excited by the cilia (see arrows) sets strongly *into* the mouth of the tube. *c* is a thick-walled enlargement of the tube, which aids the current either by its sucking or propelling power. At *d* the tube is attached to the roof of the cavity, or side of the septum, by means of a bridle of threads. From *a* to *f* the tube is single, and the contained current is single; from *f* to *e* it is complexly folded upon itself, as shown at *i*, *h* and *j*. B represents the corresponding tube in the other moiety of the segment, in outline.

Fig. 2. A view of two generative (a and a^2) and three pairs (f, g, h) of non-generative or ordinary segmental organs from *Nais filiformis*; a k is the male organ; a^2 b is the female. The masses i, j are testes; b, c are the ovaria; k, e denote the umbrella-shaped internal extremities of the generative ciliated tubes, a k and a^2 b. The dilated portions, a l, a^2 c, act as organs of expulsion to the generative products. On comparison it will be at once seen that every part of the generative segmental organ has an exact counterpart in the ordinary or non-generative organs, f, g, g h. The one therefore is only a modification of the other.

Fig. 3. A view of the generative and non-generative segmental organs of *Lumbricus Jordanii* (mihi); a, a^2, attached ends; g, c, dilated portion; f, testes; b, b, ovaria; d, coiled highly ciliated tube terminating in a pyriform open extremity, e and i; k, bridle.

j m, j m, a pair of ordinary segmental organs; B, one of the generative tubes from a young worm.

Fig. 4. The segmental organs of another species of *Lumbricus* in a very young state, *Lumbricus Kauii*, mihi; a, a, a, ordinary organ; B, enlarged view of the same; C, a generative segmental organ having attached to one side the reproductive masses c; a, mouth; b, outlet.

Fig. 5. One of the ordinary or non-generative segmental organs of the common Earthworm, *Lumbricus terrestris*; a^2, outlet; b, enlarged portion filled with minute entozoa, k; at j the enlarged non-ciliated portion ends, and the smooth-walled ciliated portion, j i, begins; from i to d extends a curiously camerated and highly vascular division of the tube, lined with slowly acting minute cilia. From d to e, the tube is again smooth-walled, dotted with the nuclei of cells along its walls; f, the ciliated fan-shaped termination suspended in the general cavity, having a very wide opening, as indicated by the arrows; n, g, g, main vascular trunk of the organ; h, h, botryoidal appendages.

Fig. 6. An outline view of the reproductive masses and ciliated tubes of the common Earth-worm *in situ*:—i, i, posterior testicular masses; h, its corresponding segmental organ; f, ovarian; i^3, its own segmental organ; l, calciferous glands; e, second ovarian mass with its own segmental organ; d, the third ovarian mass and organ; c, j, anterior testicular masses with their own segmental organs, b, b; a, a, ordinary segmental organs; k, median structure.

Fig. 7. Diagram showing the mode in which the duct of the testes (a) opens into the ciliated tube (b) to form a common duct (c) opening outwards at d.

Fig. 8. Shows the mode in which the ovarian masses (a) surround the ciliated tube, e b.

Plate VII.

Fig. 9. A full and complete representation, in the mature condition, of the ovarian segmental organ of the common Leech (*Hirudo officinalis*); a, a^2, the ends of the

two limbs (*g*, *c*) of the loop *b*. In *a* the ova, *j*, are large and mature; in the limb a^3, which is the true ovary and ingoing limb, they are small, pellucid (*k*) and destitute of vitellus. The arrows indicate the ova pursuing their path outwards; *d h* is the duct by which the so-called "respiratory sac" of DUGÈS, *l m*, communicates with the ingoing limb of the segmental organ; *i* is the orifice by which the sac of DUGÈS communicates with the general cavity of the body; *e f*, the vascular system of the ovarian limb.

Fig. 10. The ovarian segmental organ of *Albione muricata*, differing very triflingly from the former:—*d*, ovarian limb; *f*, immature ova; *h*, loop; *c*, duct leading from the sac, *a*; *b*, internal opening; *e*, oviduct or outgoing limb; *g*, mature ova contained in it.

Fig. 11. Segmental organ of *Arenicola piscatorum*, with its vascular appendage:—A^b, external orifice or commencement of ingoing limb, A *d*, which opens into the fundus, *c m*, of the organ; *b*, B, B^b, the outgoing limb, from which, at *n*, diverges a process by which the ova and sperm-cells are conducted into the general cavity of the body; *l* represents a large glandular organ, into which, about the middle of its course, the limb developes itself; *i h* and g^1 g^3, great vascular trunks of the organ; *e*, *e*, the great lateral blood-pouches, loop-shaped; *k*, capillary plexus, by which the body of the organ is supplied with blood.

Fig. 12. Two segmental organs (from the same side) of *Terebella nebulosa*. B, full-drawn; A, in outline, to show the course of the internal ciliary currents. Each organ is divided into two well-marked halves. B *m m*, dark glandular and ingoing half; *n n*, light-coloured, membranous, outgoing half; *f*, true seat of ovogenesis with its complex vascular apparatus, *h*; at *e* diverges the tube along which the ova and spermatozoa find their way into the general cavity.

Fig. 13. Segmental organ of *Sabella alveola*, viewed as a transparent object, differing in several respects from that of *Terebella*:—*a*, ingoing limb; *f g e*, vascular appendage; *d*, fundus of the loop; *d b*, outgoing limb; *c*, point at which the ova enter the reproductive appendage; *h*, ova; *i*, spermatozoa.

Fig. 14. Two segments of the body (near the tail) of a very young *Nereis margaritacea*, showing the relative position of the segmental organs, *d*, *d*, *d*, *d*, viewed as a transparent object, under strong pressure:—*c*, *c*, sacculi of the intestine; *d*, *d*, ingoing limbs of the segmental organs; *a*, fundus; *e e*, vascular appendage; *b*, long tubular outgoing limb.

Fig. 15. Vertical section of one half (left) of a ring or segment of the body of a full-sized female *Nereis margaritacea*, and looked at from the side, showing the relative places of the appended ovarian mass, *g i e*, and the segmental organ; *a b d*, intestine.

Fig. 16. The cirrus A of the former figure enlarged, representing the intimate blending of the ovarian mass, *d e c*, and the vessels, *b*.

Fig. 17. Vertical section through the entire body of *Aricia Cuvieri*, giving a correct view of the relative position of the viscera. Dark centre, intestine; above it, section of dorsal artery; *i*, *i*, ingoing limbs of segmental organs; *j*, *j*, outgoing limbs of the same; *a h c*, the great ovarian mass filling the cavity of the body and the hollow bases of the feet; *e e*, branchiæ; *f*, *g*, setiferous feet.

Fig. 18. Two rings, viewed as transparent objects under pressure, from the posterior third of the body of *Nerine* vel *Spio vulgaris*, exemplifying the exact position of the segmental organs in the segmental chambers:—*a*, *a*, mouths of ingoing limbs; *b*, *b*, vascular appendage; *c*, *c*, outgoing tubular limb.

Plate VIII.

Fig. 19. One (a male) of the segmental organs of *Spio vulgaris*, figured separately, in order to illustrate the mode in which the appended testicular mass, *c c c*, clings to and arises from the ciliated tubes, *a b*; *d*, the trunk of the associated vascular apparatus.

Fig. 20. Segmental organ of *Eunice gigantea*:—*b*, the ingoing limb; *e*, fundus; *a*, outgoing limb; *c*, the vascular tuft which supplies the ovarian limb with blood; *d*, branchial heart.

Fig. 21. Segmental organ and appended germinal mass of *Psamathe fusca*:—*a*, ingoing limb; *b*, outgoing limb; *c*, fundus; *d*, vascular appendage; *e e*, gland-like testicular body appended thereto.

Fig. 22. Segmental organ of *Cirrhatulus Lamarckii*:—*a*, ingoing limb; *b*, outgoing limb; *c*, fundus; *d*, vascular appendage.

Fig. 23. Male and female segmental and reproductive systems of *Chloræma Dujardinii*. First is to be noticed the long horizontal loop *a a*, *a b*, having its turn or fundus at *a*; then the two secondary or lateral loops, *j*, *j*; to each of these loops is appended a separate germinal mass, *e*, *e*, *e*; the ingoing limb of the long horizontal loop, *b c*, is filled with pellucid, transparent ova, and is of thrice the diameter of the other, *a a*, which is of a dark colour: the appended masses are filled with ova in the female, A, and sperm-cells in the male, B; *c*, enlarged view of the tube *a*; *c* B, sperm-tube.

Fig. 24. A, two ovarian or female segmental organs of *Polia quadrioculata*:—*a*, *a*, *a*, alimentary or stomachal cæca; *b*, *b*, segmental organs filled with ova; B, enlarged view of the same.

Fig. 25. A complete diagram of the segmental and reproductive system of *Planarea lactea*:—*a*, œsophagus; *b*, central sac in which meet the two segmental testicular organs, *e*, *e*; *c*, central sac in which meet the two branched ovarian segmental organs, *d d*, *f f*; B, a small portion of an ovarian tube enlarged.

Fig. 26. A complete view of the alimentary and segmental systems of *Aphrodita aculeata*:—*e*, termination of œsophagus; *a*, *a*, digestive cæca; *d d d*, *b b*, *c c*, branchings of segmental organs; *e*, *e*, *e*, *e*, *e*, ciliated attached ends of same.

Fig. 27. Two organs from the *Polynoe semisquamosa*:—A, female; B, male: they are simple branched cæca, commencing at a single (double?) orifice, *a*, *a*; *c*, enlarged view of ovarian tube; *d*, enlarged view of sperm-tube.

Fig. 28. Male and female segmental organs of *Aphrodita aculeata*:—A, female; B, male; *a* A, and *a* B, ciliated dilated attached ends; *b*, *b*, branches; *d*, one of the branches of the ovarian organ enlarged; *e*, bridle at one end; *d* B, a portion of the sperm-tube enlarged.

VII. *On the Partitions of the* R-*Pyramid, being the first class of* R-*gonous* X-*edra.* *By the Rev.* THOMAS P. KIRKMAN, *M.A., F.R.S., Rector of Croft with Southworth.*

Received October 14,—Read November 26, 1857.

I. As the partitions of an r-gon are made by drawing *diagonals*, so the partitions of an r-ace are made by drawing *diapeds*, each a line in two faces non-contiguous about the r-ace. A partitioned r-ace standing on a partitioned r-gon is a partitioned pyramid of r-gonal base and vertex. I am about to determine the number of such partitions of this r-pyramid, that can be made with K diapeds and k diagonals, so that no two partitions shall be syntypous; *i. e.* one the repetition or the reflected image of the other.

I have proved in a memoir "On Autopolar Polyedra" in the Transactions of the Royal Society for 1857, that the problem of the polyedra reduces itself to the determination of the x-edra generable from the r-pyramid. Such an x-edron is r-*gonous*.

Def. An r-gonous x-edral y-acron is one that by vanescence of convanescible and evanescible edges can be reduced to the r-pyramid, and cannot be so reduced to an ampler pyramid.

The definition of convanescible and evanescible edges is found at Article II. of the above-mentioned memoir, as follows:—

An edge AB is said to be *convanescible*, when neither A nor B is a triangle, and AB joins two summits which have not, besides A and B, two faces, one in each summit, collateral, nor covertical.

An edge ab is said to be *evanescible*, when neither a nor b is a triace, and the two faces about ab are not, one in each, in two summits, besides a and b, collateral, nor in one face.

II. Theorem. No r-gonous polyedron has an $(r+1)$-gon among its faces, nor an $(r+1)$-ace among its summits.

For if it has an $(r+1)$-gonal face, and no vanescible lines out of that face, it is an $(r+1)$-pyramid, contrary to hypothesis; and if it has such a face and such lines out of that face, these can be made to vanish, until the figure is an $(r+1)$-pyramid, *i. e.* it is $(r+1)$-gonous; contrary to hypothesis.

In the same way the theorem is proved if the figure has an $(r+1)$-ace.

Cor. No r-gonous polyedron can be reduced by vanescences (*i. e.* disappearances of convanescible and evanescible edges), to one having an $(r+1)$-gon or an $(r+1)$-ace; *i. e.* no r-gonous polyedron contains an $(r+1)$-gony.

III. The first family of r-gonous polyedra are those arising from partitioning the base and vertex of the r-pyramid, or, which is the same thing, from laying a partitioned r-ace upon a partitioned r-gon.

If we draw k *diagonals* in the base, none crossing another, and suppose the base to be a system of $k+1$ faces intersecting in those lines, we have a $(r+1)$-acral $(r+k+1)$-edron. If we next draw K *diapeds*, i. e. edges each in two non-contiguous faces about the r-ace, none of them enclosing a space, we have K new summits, and have before us a $(r+K+1)$-acral $(r+k+1)$-edron, of the class now to be considered.

Another family arises from partitioning the faces which intersect in the K diapeds, and the summits joined by the k diagonals; and a third family from the partitioning of the faces and summits upon the diapeds and diagonals which constitute the second.

The first class alone are here to be enumerated, and the question before us is to determine how many different r-gonous $(r+K+1)$-acral $(r+k+1)$-edra can be made, by laying a $(1+K)$-partitioned r-ace upon a $(1+k)$-partitioned r-gon, the r rays passing through the r angles.

IV. Theorem. Every $(r+K+1)$-acral $(r+k+1)$-edron Q, made by laying a $(1+K)$-partitioned r-ace A on a $(1+k)$-partitioned r-gon G, the r rays upon the r angles, is r-gonous.

For let it be supposed that Q is $(r+1)$-gonous: it is then a $(r+1+K)$-acral $(r+1+k)$-edron having $K-1$ diapeds and $k-1$ diagonals, the vanescence of which will reduce it to the $(r+1)$-pyramid. These $K-1$ diapeds cannot be any $K-1$ of the K diapeds of A; for of these all the K must vanish to form an r-ace, much less can $K-1$ vanish to form a $(r+1)$-ace. Nor can these diapeds be all of them edges and diagonals of G, for if G contains an $(r+1)$-gonous system of convanescibles, one at least of them must be a diagonal d, which may be made to vanish last of the $K-1$, and must give rise to an $(r+1)$-ace. But d vanishing can bring together only four edges of the r-gon; it must then bring together $r-3$ terminations of different diagonals; but if G has $r-3$ diagonals, it is reduced to triangles, in which no line is convanescible; which is contrary to hypothesis.

Therefore this $(r+1)$-gonous system of convanescibles must contain at least one ray θ of the r-ace A; and as convanescibles may vanish in any order, one by one, as may diagonals or evanescibles, this θ can be made to vanish last of the $K-1$. It must therefore at last carry at one end an $(r+1-e)$-ace, and at the other a $(2+e)$-ace. Let β, the base summit on θ, be the $(r+1-e)$-ace: this summit having only two edges of the r-gon G and but one ray θ, has $r-e-2$ diagonals of G terminating in it; wherefore

$$1+2+r-e-2=r+1-e$$

summits of G are occupied by $r+1-e$ edges of Q that meet at β, one of those summits.

The other extremity α of θ carries a $(2+e)$-ace, the edges of which are first, θ; secondly, two diapeds of A, for if θ at α meet only rays of A on one or both hands, it would be in one or two triangles, and would be not convanescible; thirdly, $e-1$ rays of A, because

$$2+e-1-2=e-1,$$

which $e-1$ rays terminate at $e-1$ summits of the r-gon G, all different from the $r+1-e$ summits above mentioned; for if an edge of the $(e+2)$-ace meet one of the $(r+1-e)$-ace, θ would be not convanescible, by definition.

We have still an account to give of the rays of A meeting in the other extremities of the two diapeds joining A in the $(r+1-e)$-ace. There must be at least a set of two rays at each of those extremities. One ray in each set will be in each non-triangular face about θ, and therefore in a face about the $(r+1-e)$-ace; another ray in each set, that most remote from θ, will be in a face about the $(2+e)$-ace, and cannot therefore meet any edge of the $(r+1-e)$-ace, because θ is convanescible; each ray must therefore pass to a summit of the r-gon not occupied by the $r-e-2$ diagonals above mentioned, and being rays of A, neither can meet any other ray on the r-gon. But $r+1-e$ summits of G have been shown to be occupied by the edges of the $(r+1-e)$-ace, and $e-1$ more by the $e-1$ rays meeting in the $(2+e)$-ace; therefore there are no summits of the r-gon remaining to which the two last considered rays can pass from separate extremities of the two diapeds meeting θ. Q. E. A.

Therefore Q is not $(r+1)$-gonous.

In the same way it can be proved *a fortiori* that Q is not $(r+1+r')$-gonous.

V. This theorem being established, at a cost of words of which I feel ashamed, our problem is reduced to the enumeration of the different figures obtainable by laying any $(1+K)$-partitioned r-ace A on any $(1+k)$-partitioned r-gon G. But we are to exclude from our reckoning any figure P′ which is the reflected image of another, P; for P′, being only P turned inside out through some face supposed open, has the same arrangements and ranks of summits and faces with P, *i. e.* is syntypous with P.

What follows will be intelligible to the reader who has before him my memoir "On the k-partitions of the r-gon and r-ace," in the Transactions of the Royal Society for 1857. These partitions can be found by formulæ there given.

VI. Let a $(1+k)$-partition A of the r-ace, having j axial planes of reversion, be laid on a $(1+k)$-partition G of the r-gon, having i axes of reversion (vide the above memoir, Art. LXXIII. and Theorems A, B, C, &c.). I call the intersection of an axial plane with the r-gon *a trace*, and by an axis I mean always an axis of reversion of the r-gon G.

If we can lay a trace upon an axis, the r rays of A passing through the r summits of G, we shall see, among the angles >0 at which the remaining traces are inclined to the axes, a certain least angle Θ. If x be the number of half-edges of the r-gon between two adjacent traces, and y that between two adjacent axes, and z that in the angle Θ, Θ is the least positive value of z in

$$ax=by\pm z,$$

a and b being numbers of these intervals x and y measured in the same direction from the united trace and axis. When x is prime to y, it is well known that $z=1$; and when x and y have m for their greatest common measure, we have

$$\frac{ax}{m}=\frac{by}{m}\pm 1$$

$$ax=by\pm m.$$

Here m is the least possible value of z; for if we say

$$ax=by\pm m-n,$$

we shall have $m-n$ divisible by m. Q.E.A.

The number x is $2r{:}2j$, and y is $2r{:}2i$, that of the half-edges of the r-gon divided by the number $2j$ or $2i$ of intervals between traces or axes. If we put

$$m=\frac{r}{j!i}$$

for the greatest common measure of $r{:}j$ and $r{:}i$, this m is the number of half-edges in Θ, the least interval >0 between a trace and an axis.

Now let Θ be diminished by an entire edge, every ray taking the place of that preceding it in the direction of revolution of the r-ace. We shall thus step by step diminish Θ either to zero or to half an edge, as m is even or odd. The combined configuration will be different at every step, because the least angle between a trace and axis is always diminished, and the configuration C carried by either end of the revolving trace is brought at each step to stand over a different configuration in the r-gon; for $m\not>$ the least interval of the two $x=r{:}j$ and $y=r{:}i$; that is, no trace is made to cross an axis by this process of diminishing Θ.

VII. When Θ has its greatest value, it is either $r{:}j$ or $r{:}i$, containing the whole interval, reckoned in half-edges, between two adjacent traces, or adjacent axes. If it is even, it can be reduced to zero, and the last position as well as the first will show a trace coincident with an axis; but whether these positions show a trace t over two adjacent axes, or an axis a under two adjacent traces, the combined configurations will be different, because the alternate axial configurations read at the terminations of either traces or axes are always different. Hence, when Θ is reduced to zero, the figure is not a repetition of a previous one.

But if we diminish Θ below zero, we shall repeat in reversed order the configurations seen when Θ was >0, $\Theta=e$ on one side of the united trace and axis giving the reflected image of the figure seen in $\Theta=-e$; as everything is reversible about the united trace and axis, when $\Theta=0$. Hence a trace is never to cross an axis in our process.

VIII. If then we can lay a trace upon an axis for a first position for Θ undiminished, we shall obtain as many additional figures by diminishing Θ by an edge at a step as there are entire edges in Θ. That is, if Θ is even, we get

$$1+\tfrac{1}{2}m=1+\tfrac{1}{2}\frac{r}{j!i}=\tfrac{1}{2}\left\{2+\frac{r}{j!i}\right\}$$

different figures; and if Θ is odd,

$$1+\tfrac{1}{2}(m-1)=\tfrac{1}{2}\left\{1+\frac{r}{j!i}\right\}$$

different figures. Or if we put

$$!\tfrac{1}{2}\mathrm{N}=\text{the greatest integer in }\tfrac{1}{2}\mathrm{N},$$

we obtain both for Θ even and Θ odd,

$$!\tfrac{1}{2}\left\{2+\frac{r}{j!i}\right\} \text{ different figures,}$$

whenever a trace can be laid upon an axis, Θ even being finally reduced to zero, and Θ odd to half an edge.

But if A has only diachorial traces and G only diagonal axes, or if A has only achorial traces and G only agonal axes, we can lay no trace upon an axis, if the r rays pass through the r angles of G. Our first position will therefore show the Θ reckoned as above diminished by half an edge, and our last position will show Θ diminished to half an edge. Wherefore Θ must be even, as is also evident from the consideration that the interval between either two traces or two axes in these cases is an even number of half-edges, so that their greatest common measure is even. Hence the number of figures obtainable by the reduction of Θ is one less than that obtained above for Θ even, *i. e.*

$$\tfrac{1}{2}m=\tfrac{1}{2}\frac{r}{j!i}$$

is the number of different figures attainable, when no trace can be laid upon an axis, by laying A upon G in every possible way.

Now we can always lay a trace upon an axis, unless either the traces are all achorial and the axes all agonal, or the traces are all diachorial and the axes are all diagonal.

IX. Hence we have the Theorem:

The number of $(r+\mathrm{K}+1)$-acral $(r+k+1)$-edra that can be made by laying

A one of $\mathrm{R}^{j\mathrm{Dt}}(r,\mathrm{K})$ on G one of $\mathrm{R}^{i\mathrm{dt}}(r,k)$, or
A one of $\mathrm{R}^{j\mathrm{Ac}}(r,\mathrm{K})$ on G one of $\mathrm{R}^{i\mathrm{ag}}(r,k)$,

$$\text{is } \tfrac{1}{2}\cdot\frac{r}{j!i};$$

and the number of them obtainable in every other case by laying a j-ly reversible $(1+k)$-partition A of the r-ace on an i-ly reversible $(1+k)$-partition G of the r-gon is

$$!\tfrac{1}{2}\left\{2+\frac{r}{j!i}\right\};$$

where $\frac{r}{j!i}$ is the greatest common measure of $r{:}j$ and $r{:}i$, and $!\tfrac{1}{2}\mathrm{N}$ is the greatest integer in $\tfrac{1}{2}\mathrm{N}$.

X. Now let A, a $(1+\mathrm{K})$-partition of the r-ace reversible about j axial planes, be laid on G, an i-ly irreversible $(1+k)$-partition of the r-gon.

If we lay A in any way on G, so that the r rays pass through the r angles of G, we see at p, the termination of a certain trace, a configuration G′ in G under the axial configuration A′ in A. This A′ is seen in Aj times, at half the $2j$ terminations of traces; and G′ is seen in G i times, at the first point of each of the i equal irreversible sequences that are read round the r-gon, beginning at p. Let Θ' be the number of entire edges between that A′ and G′ that are nearest to each other without coincidence, observed in

our first position of A on G. Then, if we reduce Θ' by an edge at once, till it is only a single edge, we shall obtain Θ' different combined configurations; because no two of them show the same distance measured in the same direction between the A′ and G′ nearest each other. If we reduce Θ' to zero, we see again G′ under A′, as in our first position, and begin here a series of steps that reproduce the previous figures. Hence the exact number of different results is Θ', the least value of z in

$$a\frac{r}{j}=b\frac{r}{i}\pm z,$$

the numbers a and b of intervals $r.j$ and $r.i$ of whole edges from A′ to A′ and from G′ to G′ being measured from p. This z is the greatest common measure of $r.j$ and $r.i$, i. e.

$$\Theta'=\frac{r}{j.i} \text{ whole edges.}$$

Wherefore this is the number of different figures obtained by laying one of $R^j(r, K)$ on one of $I^i(r, k)$, and the same exactly is that obtained by laying one of $I^j(r, K)$ on one of $R^i(r, k)$. No new figures can be obtained by reversing the irreversible G, or by turning inside out the irreversible A, because A in the first, and G in the second, of these cases being reversible, we shall merely obtain by that reversal a reflected image of the figure before the reversal.

XI. It remains that we lay A one of $I^j(r, K)$ on G one of $I^i(r, k)$, an irreversible on an irreversible.

A being laid in any way on G, we see at a certain point p the configuration A″ over the configuration G″. A″ is found in A j times, and G″ in G i times. The least interval in whole edges >0 between an A″ and a G″ in our first position is the least value of z in

$$a\frac{r}{j}=b\frac{r}{i}\pm z,$$

$r.j$ being the number of rays in one irreversible sequence in A, and $r.i$ that of summits in one irreversible sequence in G. A[illegible] we have

$$z=\frac{r}{j.i}$$

for the number of different figures, [illegible]ach showing a different distance measured in one direction, between the nearest A″ and [illegible]″. If we now either reverse G, or turn A inside out, we can double this number of resu[illegible]s, [illegible] A in the first case and G in the second being irreversible, we obtain figures which are not reflected images of preceding ones. Wherefore the entire number of figures obtainable is

$$2\cdot\frac{r}{j.i},$$

by laying any one A of $I^j(r, K)$ upon any one G of $I^i(r, k)$.

Collecting our results, we have shown that there are

$$\tfrac{1}{2}\left\{2+\frac{r}{j!i}\right\} \text{ ways of laying}$$

A one of $R^{jDi}(r, K)$ on G one of $R^{iag}(r, k)$ or of $R^{iagdi}(r, k)$,

or A one of $R^{jAc}(r, K)$ on G one of $R^{idi}(r, k)$ or of $R^{iagdi}(r, k)$,

or A one of $R^{jAcDi}(r, K)$ on G one of $R^{iag}(r, k)$, $R^{idi}(r, k)$ or $R^{iagdi}(r, k)$,

or A one of $R^{jMo}(r, K)$ on G one of $R^{imo}(r, k)$.

And there are

$$\tfrac{1}{2}\frac{r}{j!i} \text{ different ways of laying}$$

A one of $R^{jDi}(r, K)$ on G one of $R^{idi}(r, k)$,

or A one of $R^{jAc}(r, K)$ on G one of $R^{iag}(r, k)$.

Also there are

$$\frac{r}{j!i} \text{ different ways of laying}$$

A any one of $R^{j}(r, K)$ on G any one of $I^{i}(r, k)$,

or A any one of $I^{j}(r, K)$ on G any one of $R^{i}(r, k)$.

And there are

$$2\cdot\frac{r}{j!i} \text{ different ways of laying}$$

A any one of $I^{j}(r, K)$ on G any one of $I^{i}(r, k)$.

XII. It is certain that, in every one P of these figures, the configuration with respect to the r-gon 1 2 3..r, is different from that seen with respect to the r-gon 1 2 3..r upon any other figure P′. But it remains to be considered whether there may not be on P another closed r-gon, whose summits are not 1 2 3..r, about which is seen that configuration which we read on P′ about the r-gon 1 2 3..r. If this be so, the $(r+K+1)$-acral $(r+k+1)$-edron P may be merely the $(r+K+1)$-acral $(r+k+1)$-edron P′. That is, P may be reducible by vanescence to two $(r+1)$-edral pyramids not having the same signatures, and may be considered as A laid upon G, or as A′, a differently partitioned r-ace from A, laid on G′, a differently partitioned r-gon from G.

If P has this double character, I call it a *bigenerate* r-gonous $(1+K)$-acral $(1+k)$-edron; and if it can be made by laying A on G, and by laying A′ on G′, and by laying A″ on G″, &c., I call it a *multigenerate*.

XIII. We are thus compelled to inquire, how many *multigenerates of the first class* can be made by laying a $(1+K)$-partitioned r-ace on a $(1+k)$-partitioned r-gon; for as we are enumerating only those of the first class, we have no repetitions to fear out of it.

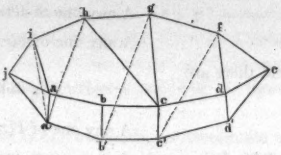
It is true that some of these $(r+K+1)$-acral $(r+k+1)$-edra of the first r-gonous class, are also $(r+K+1)$-acral $(r+k+1)$-edra of the second; as A′ having $K-e$ diapeds, and laid on G′ having k diagonals, and also e diapeds of the second class, may give the same polyedron with A having K diapeds, laid on G having k diagonals. This will perplex the discussion of the second class, but does not trouble us here.

Let Q be such a multigenerate, made by laying A on G, and by A′ on G′, &c. As A is not A′, the r rays of A′ will not comprise all those of A; nor can they be all diapeds of A, for A cannot have more than $r-3$ diapeds; nor can they all be found among the sides and diagonals of G, for it is impossible to make above $r-1$ edges and diagonals by any arrangement or convanescences to meet at one summit of G; while A′ is reducible by convanescence to an r-ace. Wherefore $\varrho(>0, <r)$ of the rays of A must be also rays of A′.

Let these ϱ common rays be aa_ρ, bb_ρ, cc_ρ, dd_ρ, ..., the points $a\,b\,c\,d$... being summits of G′, and $a_1b_1c_1d_1$... summits of G. If the K diapeds of A convanesce, A becomes a simple r-ace R standing on G the r-gon $a_1\,b_1\,c_1\,d_1$..., wherefore ab, bc, cd, ... are diapeds of A; and in like manner $a_\rho b_\rho$, $b_\rho c_\rho$, $c_\rho d_\rho$... are diapeds of A′. When A is reduced to the simple r-ace R, there are no summits of the figure on the side of the r-gon $a_1\,b_1\,c_1\,d_1$... remote from R, since A is laid on the partitioned r-gon $a_1\,b_1\,c_1\,d_1$...; and if A′ be reduced to the simple r-ace R′, there are no summits in the figure on the side of the r-gon $a\,b\,c\,d$... remote from R′. Hence Q, the figure A upon G, is of this form, for the case $r=10$.

Here G is the 10-gon $a_1b_1c_1d_1efghij$,

G′ is the 10-gon $a\,b\,c\,d\,e\,f\,g\,h\,i\,j$;



The ϱ common rays are aa_1 bb_1 cc_1 dd_1; ($\varrho=4$)

The diapeds of A are ab, bc, cd;

The diapeds of A′ are a_1b_1 b_1c_1 c_1d_1;

The diagonals of G are a_1i, a_1h, b_1g, c_1f, all rays of A′;

The diagonals of G′ are ai, ch, cg, df, all rays of A.

The number of these diagonals, along with the ϱ common rays and the lines aj and de, must make up in A′ the r rays, *i. e.*

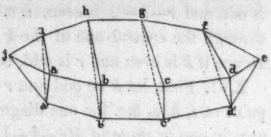
$$k=r-\varrho-2,$$

of which one must pass through each of the $r-\varrho-2$ summits of G′ $f\,g\,h\,i$, which are also summits of G through which pass the rays of A, ai, ch, cg, df. The number of diapeds in either A or A′ is

$$K=\varrho-1=r-k-3.$$

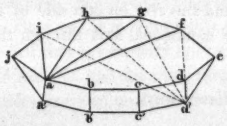
XIV. The condition to be fulfilled in drawing the diagonals of G is, that all the $\varrho-1$ lines ab, bc, cd shall be diapeds, *i. e.* none of them in a triangle, and the diagonals of G′ must be so drawn that all the lines a_1b_1 b_1c_1 c_1d_1 shall be also convanescible. If these conditions are fulfilled, the figure is bigenerate, otherwise it is not. This condition is fulfilled, if the k rays of A from $i\,h\,g\,f$ be drawn in any manner not crossing one another to one or more of the ϱ summits $a\,b\,c\,d$, and if the k rays of A′ from $i\,h\,g\,f$ are drawn in any manner not crossing one another to any of the summits $a_1\,b_1\,c_1\,d_1$. For example, the rays of A, or rather the diagonals of G′, may be drawn all to a, viz. ai, ah, ag, af; the lines ab, bc, cd will be convanescible, being three sides of an open 6-gon $a\,b\,c\,d\,e\,f$; and thus it is easily seen that these k diagonals of G′ through $i\,h\,g$ and f may be distributed in any manner upon the summits $a\,b\,c\,d$.

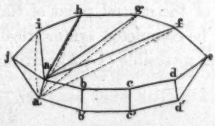
Such a figure Q can only be bigenerate; for suppose that it was trigenerate, made by laying A on G, or A′ on G′, or A″ on G″. Then it is proved that A and A″ have $\varrho=r-k-2$ common rays, and that the only diapeds of A are *ab*, *bc*, *cd* ...; hence the rays common to A and A″ must be *ai*, *bh*, *cg*, *df* ..., and the figure must be of the form



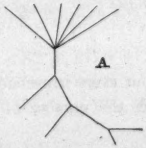
But this is not properly multigenerate, the three 10-gons *jihgfedcba*, *jihgfed*$_{\prime}c_{\prime}b_{\prime}a_{\prime}$, and *jabcded*$_{\prime}c_{\prime}b_{\prime}a_{\prime}$, being all the same partition G, surmounted by the same partitioned 10-ace A. A 4-generate Q is here entirely out of question; for the figure must reduce, by the convanescence of the $r-k-2$ diapeds of A, to a simple r-ace standing on G having k diagonals. Wherefore the Q to be considered here is bigenerate only.

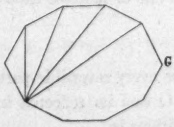
XV. We shall know the number of bigenerates, if we determine in how many *different ways* these k diagonals drawn from k consecutive summits of the r-gon can terminate at the $r-k-2$ summits $a\,b\,c\,d$. But if G and G′ had the same arrangement of their k diagonals, or if one were merely the reflected image of the other, we should have a figure generated by A upon G only, *i. e.* a figure that we have constructed and counted only once among those made by laying (K+1)-partitioned r-aces upon $(k+1)$-partitioned r-gons. For example, neither of the two figures following





has been twice enumerated; for whether we take *ab*, *bc*, and *cd*, or $a_{\prime}b_{\prime}$, $b_{\prime}c_{\prime}$ and $c_{\prime}d_{\prime}$ for the diapeds in either, we find indeed A on G and A′ on G′, but A differs in no respect from A′, nor G from G′, nor is there any difference in the way of applying the A to the G. Either of them is made by laying in one way only the 4-partitioned 10-ace A on the 5-partitioned 10-gon G, here given separately.





The $(1+k)$-partitions now to be enumerated may be either reversible or irreversible. If k is odd and $\varrho=r-k-2$ is odd also, that is, if r is even and k is odd, one of the k diagonals may be a diameter about which the partition is reversible. If k is even, and ϱ, i. e. r, is either even or odd, the partition may be reversible about either an agonal

or a monogonal axis; $\frac{1}{2}k$ diagonals being similarly drawn on either side of it. But if k is odd and $r-k-2$ is even, *i. e.* if r be odd, no axis but a monogonal can be drawn through the central one of the k summits i, h, g, &c., which axis cannot be a diagonal. Hence if k is even and r is odd, the partition cannot be reversible.

XVI. First, let k be odd and r even. We can draw a diameter δ through the central point of i, h, g, &c. for one diagonal, and can draw $\frac{1}{2}(k-1)$ on one side of δ to terminate in one or more of $\frac{1}{2}(r-k-1)$ summits, viz. the central point of $a\,b\,c\ldots$ and those on one side of it, in

$$\frac{\left(\frac{1}{2}(r-k-)\right)^{\underline{k(k-1)|1}}}{\underline{|\frac{1}{2}(k+1)}}$$

different ways, and the figure can be completed symmetrically about δ in so many ways into a reversible $(1+k)$-partition.

If k is even and r is even, we can draw $\frac{1}{2}k$ of the diagonals to one or more of the corresponding half of the $r-k-2$ summits i, h, g, &c. in

$$\frac{\frac{1}{2}(r-k-2)^{\underline{k|1}}}{\underline{|\frac{1}{2}(k+2)}} \text{ different ways,}$$

and complete the figure by drawing the remaining $\frac{1}{2}k$ into a $(1+k)$-partition reversible about an agonal axis having on each side of it $\frac{1}{2}k$ diagonals.

If k is even and r is odd, we can draw $\frac{1}{2}k$ of the diagonals to the $\frac{1}{2}(r-k-1)$ points consisting of the central point of the $r-k-2$, and the rest on one side of it, and the figure can be completed symmetrically about the monogonal axis through that central point into a reversible $(1+k)$-partition, in

$$\frac{\left(\frac{1}{2}(r-k-1)\right)^{\underline{k|1}}}{\underline{|\frac{1}{2}(k+2)}} \text{ different ways.}$$

Wherefore the entire number of reversible ways of drawing k diagonals from k consecutive summits i, h, $g\ldots$ to one or more of the $(r-k-2)$ summits a, b, $c\ldots$, is

$$N'_{r,k}=2_r\left\{2_{k-1}.\frac{\left(\frac{1}{2}(r-k-1)\right)^{\underline{k(k-1)|1}}}{\underline{|\frac{1}{2}(k+1)}}+2_k\frac{\left(\frac{1}{2}(r-k-2)\right)^{\underline{k|1}}}{\underline{|\frac{1}{2}(k+2)}}\right\}+2_{r-1}2_k.\frac{\left(\frac{1}{2}(r-k-1)\right)^{\underline{k|1}}}{\underline{|\frac{1}{2}(k+2)}}.$$

The entire number of ways in which k diagonals can be drawn from the k points $i, h, g, \ldots$ to one or more of the $r-k-2$ points $a\,b\,c\ldots$, is

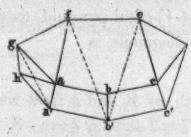
$$\frac{(r-k-2)^{\underline{k|1}}}{\underline{|k+1}}:$$

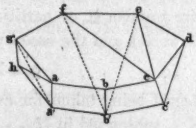
among these every reversible partition comes once only, but every irreversible Q occurs twice; for Q and its reflected image both occur. Hence the number of irreversible $(1+k)$-partitions is

$$N''_{r,k}=\frac{1}{2}\left\{\frac{(r-k-2)^{\underline{k|1}}}{\underline{|k+1}}-N'_{r,k}\right\}.$$

XVII. Of these $N'_{r,k}$ reversible modes of partition any one can be combined in G with any other in G′, giving $\frac{1}{2}N'_{r,k}(N'_{r,k}-1)$ pairs, and as many bigenerates, which have been each twice constructed and counted. Of these $N'_{r,k}$ modes any one may be combined

in G with any of the irreversibles in G′, giving $N'_{r,k}\,N''_{r,k}$, and as many bigenerates. Of the $N''_{r,k}$ irreversible partitions any one in G may be combined with another in G′, and again with that reversed, so that each of the $\frac{1}{2}N''_{r,k}(N''_{r,k}-1)$ pairs gives two bigenerates. For example, the two bigenerates





have each the same irreversible partition G on the lower side in the same position, and each the same irreversible partition G′ above, but in positions one the reverse of the other.

Hence the entire number of bigenerates is

$$N_{r,k}=\tfrac{1}{2}N'_{r,k}(N'_{r,k}-1)+N'_{r,k}\,N''_{r,k}+N''_{r,k}(N''_{r,k}-1),$$

where N′ and N″ have the values just found.

And this number $N_{r,k}$ is to be subtracted from the results of our enumeration by preceding formulæ, being the exact number of $(r+K+1)$-acral $(r+k+1)$-edra that were twice constructed, each one Q being made both by laying A upon G, and A′ upon G′.

XVIII. Thus we have completely determined all the partitions of the $(r+1)$-edral pyramid. All that is necessary is to give to k every value from $k=0$ to $k=r-3$ in the formulæ of Art. XI. and the same range of values to K; then to give to k in the two preceding articles every value from $k=1$ to $k=r-4$; for here since neither k nor $K<1$, $k=r-K-3\not>r-4$.

And we have at once the number of r-gonous $(r+K+1)$-acral $(r+k+1)$-edra of the first class, by giving to k and K their values in (XI.) and (XVII.). That is, if $\Pi_{r,K,k}$ be this number,

$$\begin{aligned}\Pi_{r,K,k}=\Sigma_j\Sigma_i\Big[&\Big\{R^{jAcDi}(r,K)\big(R^{ingdi}(r,k)+R^{ing}(r,k)+R^{idi}(r,k)\big)\\&+R^{jAc}(r,K)\big(R^{ingdi}(r,k)+R^{idi}(r,k)\big)+R^{jDi}(r,K)\big(R^{ingdi}(r,k)+R^{ing}(r,k)\big)\\&+R^{jMo}(r,K).R^{imo}(r,k)\Big\}\times!\tfrac{1}{2}\Big(2+\tfrac{r}{j!i}\Big)+\{R^{jAc}(r,K).R^{ing}(r,k)+R^{jDi}(r,K).R^{idi}(r,k)\}\times\tfrac{1}{2}.\tfrac{r}{j!i}\\&+\{I^{j}(r,K).R^{i}(r,k)+R^{j}(r,K).I^{i}(r,k)\}.\tfrac{r}{j!i}+2I^{j}(r,K).I^{i}(r,k).\tfrac{r}{j!i}\Big]\\&-(N_{r,k}=)\big(\tfrac{1}{2}.N'_{r,k}(N'_{r,k}-1)+N'_{r,k}.N''_{r,k}+N''_{r,k}(N''_{r,k}-1)\big);\end{aligned}$$

where $\frac{r}{j!i}$ is the greatest common measure of $\frac{r}{j}$ and $\frac{r}{i}$, and $!\frac{1}{2}A$ is the greatest integer in $\frac{1}{2}A$, and where $R^{j}(r,k)$ denotes the entire number of j-ly reversibles about all axes, the rest of the notation here used being that of my paper referred to in Art. V.; and where

$$N'_{r,k}=2_r\left\{2_{k-1}.\frac{\left(\frac{1}{2}(r-k-1)\right)^{\underline{k(k-1)|1}}}{\left|\frac{1}{2}(k+1)\right.}+2_k\frac{\left(\frac{1}{2}(r-k-2)\right)^{\underline{k|1}}}{\left|\frac{1}{2}(k+2)\right.}\right\}+2_{r-k}.2_k\frac{\left(\frac{1}{2}(r-k-1)\right)^{\underline{k|1}}}{\left|\frac{1}{2}(k+2)\right.},$$

and

$$N''_{r,k}=\tfrac{1}{2}\left\{\frac{(r-k-2)^{\underline{k|1}}}{k+1}-N'_{r,k}\right\}.$$

And the entire number $\mathfrak{D}_r$ of partitions of the $(r+1)$-edral pyramid, made by partitioning both the vertex and the base by diapeds and diagonals, is

$$\mathfrak{D}_r=\Sigma_K\Sigma_k\Pi_{r,K,k},$$

the double integral being taken for every value both of K and k from zero to $r=3$. The quantity $N_{r,k}$, subtracted in $\Pi_{r,K,k}$, vanishes for $k=0$ and for $k=r-3$.

XIX. Thus far the theory of the polyedra has been opened and discussed without descending to any classification according to the ranks of the faces and summits. We have had nothing but an r-ace and an r-gon to partition. But I do not see how the second and higher classes of r-gonous x-edra can be enumerated without such a classification. This will, I fear, introduce a boundless complexity, and go far to deprive the investigation of all claim to scientific generality. Yet others may find out a more practicable method of attacking this interesting problem, and I may live to see the remaining cases of it discussed within a reasonable compass. I wish the analyst joy of his task who shall undertake to complete what I have had the good fortune to begin.

XX. I have no doubt that the number of r-gonous x-edra is always limited; but the maximum number of their edges is no simple function of r. It is worth while to write out all the 4-gonous polyedra.

These are, first and second,—

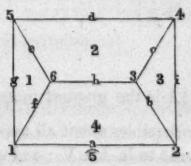
$$3_1\mathbf{4}_4 3_2\mathbf{4}_5 \quad 3_2\mathbf{4}_4 3_3\mathbf{3}_3 \quad 3_3\mathbf{4}_2 3_4\mathbf{3}_3 \quad 3_4\mathbf{4}_2 3_5\mathbf{4}_5 \quad 3_5\mathbf{4}_2 3_6\mathbf{3}_1 \quad 3_6\mathbf{4}_4 3_1\mathbf{3}_1$$
$$3_5\mathbf{3}_1 3_1\mathbf{4}_5 \quad 3_6\mathbf{4}_2 3_3\mathbf{4}_4 \quad 3_2\mathbf{3}_3 3_4\mathbf{4}_5,$$

a 6-acral 5-edron, and its polar syntyp,—

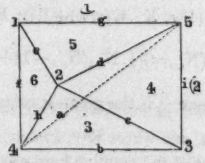
$$\mathbf{3}_1 4_4\mathbf{3}_2 4_5 \quad \mathbf{3}_2 4_4\mathbf{3}_3 3_3 \quad \mathbf{3}_3 4_2\mathbf{3}_4 3_3 \quad \mathbf{3}_4 4_2\mathbf{3}_5 4_5 \quad \mathbf{3}_5 4_2\mathbf{3}_6 3_1$$
$$\mathbf{3}_6 4_4\mathbf{3}_1 3_1 \quad \mathbf{3}_5 3_1\mathbf{3}_1 4_5 \quad \mathbf{3}_6 4_2\mathbf{3}_3 4_4 \quad \mathbf{3}_2 3_3\mathbf{3}_4 4_5.$$

The heavy type expresses the faces, and the lighter the summits.

Both are thus represented in one paradigm, by the method explained in my paper "On the Representation of Polyedra," in the Philosophical Transactions for 1856, using the circles 123456 and 12345, and writing a at (1, 4) and (2, 5), &c.:



f	.	.	.	g	e
.	.	c	d	e	h
.	i	b	c	.	.
a	b	h	.	.	f
g	a	.	i	d	.

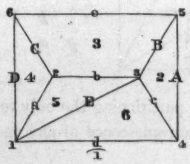


Both these are of the first class of 4-gonous polyedra, the only one besides of this class being the autopolar 6-acral 6-edron. This is,—

$$4_1\mathbf{3}_4\mathbf{3}_2\mathbf{3}_5 \quad 3_2\mathbf{4}_3\mathbf{4}_3\mathbf{3}_5 \quad 4_3\mathbf{3}_3\mathbf{3}_4\mathbf{3}_6 \quad 3_4\mathbf{4}_1\mathbf{4}_1\mathbf{3}_6 \quad 3_5\mathbf{4}_3\mathbf{3}_6\mathbf{4}_1$$
$$\mathbf{4}_1\mathbf{3}_4\mathbf{3}_2\mathbf{3}_5 \quad \mathbf{3}_2\mathbf{4}_3\mathbf{4}_3\mathbf{3}_5 \quad \mathbf{4}_3\mathbf{3}_3\mathbf{3}_4\mathbf{3}_6 \quad \mathbf{3}_4\mathbf{4}_1\mathbf{4}_1\mathbf{3}_6 \quad \mathbf{3}_5\mathbf{4}_3\mathbf{3}_6\mathbf{4}_1,$$

which is also thus represented, using the circles 123456, 123456, and putting A for the gamic of *a*, &c.,—

D	.	.	*d*	A	*e*
.	.	*c*	A	B	.
.	*b*	B	.	*e*	C
a	C	.	.	.	D
E	*a*	*b*	.	.	.
d	.	E	*c*	.	.



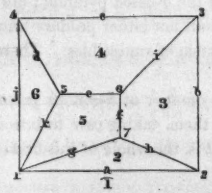
which reduces by the gamic pair E*e* to the pyramid on 1234.

The fourth and fifth are a sympolar pair, a 6-acral 7-edron, and a 7-acral 6-edron, of the second class of 4-gonous *x*-edra, made by partitioning a 4-gon or a 4-ace in the preceding autopolar so as to introduce no pentace or pentagon. Thus,

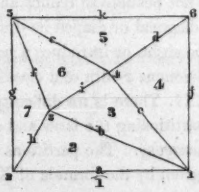
$$4_1\mathbf{3}_2\mathbf{3}_2\mathbf{4}_1 \quad 3_2\mathbf{4}_3\mathbf{3}_3\mathbf{4}_1 \quad 3_3\mathbf{4}_4\mathbf{3}_4\mathbf{4}_1 \quad 3_4\mathbf{4}_4\mathbf{3}_5\mathbf{3}_6 \quad 3_5\mathbf{4}_4\mathbf{3}_6\mathbf{4}_5 \quad 3_6\mathbf{4}_5\mathbf{3}_7\mathbf{4}_5$$
$$3_7\mathbf{3}_2\mathbf{4}_1\mathbf{4}_5 \quad 3_7\mathbf{4}_3\mathbf{3}_2\mathbf{3}_2 \quad 3_3\mathbf{4}_3\mathbf{3}_6\mathbf{4}_4 \quad 4_1\mathbf{4}_1\mathbf{3}_4\mathbf{3}_6 \quad 4_1\mathbf{3}_6\mathbf{3}_5\mathbf{4}_5,$$

$$\mathbf{4}_1\mathbf{3}_2\mathbf{3}_2\mathbf{4}_1 \quad \mathbf{3}_2\mathbf{4}_3\mathbf{3}_3\mathbf{4}_1 \quad \mathbf{3}_3\mathbf{4}_4\mathbf{3}_4\mathbf{4}_1 \quad \mathbf{3}_4\mathbf{4}_4\mathbf{3}_5\mathbf{3}_6 \quad \mathbf{3}_5\mathbf{4}_4\mathbf{3}_6\mathbf{4}_5 \quad \mathbf{3}_6\mathbf{4}_3\mathbf{3}_7\mathbf{4}_5$$
$$\mathbf{3}_7\mathbf{3}_2\mathbf{4}_1\mathbf{4}_5 \quad \mathbf{3}_7\mathbf{4}_3\mathbf{3}_2\mathbf{3}_2 \quad \mathbf{3}_3\mathbf{4}_3\mathbf{3}_6\mathbf{4}_4 \quad \mathbf{4}_1\mathbf{4}_1\mathbf{3}_4\mathbf{3}_6 \quad \mathbf{4}_1\mathbf{3}_6\mathbf{3}_5\mathbf{4}_5,$$

both which are seen in the paradigm made by the circles 1234567 and 123456, as follows:—



j	*a*	*b*	*c*	.	.	.
a	*h*	.	.	.	.	*g*
.	*b*	*i*	.	.	*f*	*h*
.	.	*c*	*d*	*e*	*i*	.
g	.	.	.	*k*	*e*	*f*
k	.	.	*j*	*d*	.	.

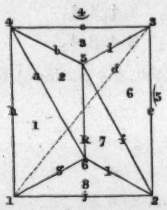


The sixth and seventh are the regular 6-edron and its polar syntyp the regular 8-edron, both of the second class, the first represented by writing under 3**4**3**4** the 12 quadruplets

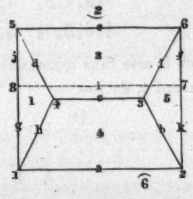
1426 2435 3443 4153 5263 6275 7286 8116 1144 8251 3365 7625,

and the second by writing under **3**43**4** the same 12 quadruplets. Both are exhibited

thus by using the circles 12345678, the closed octagon through the summits of the 6-edron, and 123456, the hexagon on the faces:—



h	.	.	*d*	*j*	.	.	*g*
.	.	.	.	*e*	*f*	*l*	*j*
.	.	*i*	*c*	*d*	*e*	.	.
a	*b*	*c*	*h*	.	.	.	.
.	*k*	*b*	.	.	*i*	*f*	.
g	*a*	.	.	.	.	*k*	*l*

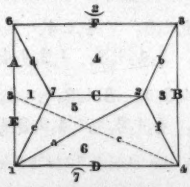


This arises from partitioning the only tesserace in the preceding 7-acron, and is reduced to that by the convanescence of any one of its twelve edges. It is also of the second class.

The eighth is an autopolar heptaedron,—

$4_1\mathbf{3}_5 4_3\mathbf{3}_6$ $4_2\mathbf{4}_4 3_3\mathbf{3}_3$ $4_4\mathbf{4}_2 3_5\mathbf{3}_7$ $3_6\mathbf{4}_4 3_7\mathbf{4}_1$ $3_7\mathbf{3}_5 4_1\mathbf{4}_1$ $4_2\mathbf{3}_3 4_4\mathbf{3}_6$

$3_5\mathbf{4}_2 3_6\mathbf{4}_1$ $4_4\mathbf{3}_3 3_3\mathbf{4}_2$ $4_2\mathbf{3}_5 3_7\mathbf{4}_4$ $4_4\mathbf{3}_7 4_1\mathbf{3}_6$ $3_5\mathbf{4}_1 4_1\mathbf{3}_7$ $3_3\mathbf{4}_4 3_6\mathbf{4}_2$



e	.	.	.	E	A	*d*
.	.	B	*c*	A	F	.
.	*f*	*b*	B	.	.	.
.	*b*	F	.	.	*d*	C
a	C	.	.	.	.	*e*
D	*a*	.	*f*	.	.	.
E	.	.	D	*c*	.	.

It is not possible to reduce any of these eight polyedra to the 5-based pyramid; nor can any diagonal or diaped be drawn in any of them which shall not either produce another of the eight, or introduce a *pentagony*, i. e. a 5-gonous system of vanescibles. There are no 4-gonous x-edra of a class beyond the second.

XXI. There is no difficulty in finding tentatively the number of 5-gonous polyedra, by partitioning the faces and summits of the first class of them, taking care to introduce no *hexagony*. The partitions of the 5-based pyramid, that is, the whole of this first class, are given by the formula of XVIII., in which

$$N'_{5,1}=0 \quad N''_{5,1}=1, \quad N'_{5,2}=1, \quad N''_{5,2}=0,$$

i. e.

$$N_{5,1}=0=N_{5,2}.$$

And the only partitions of the 5-gon are $R^{\text{sno}}(5, 0)=1$, $R^{\text{no}}(5, 1)=1$, $R^{\text{no}}(5, 2)=1$. Wherefore

$$\mathfrak{D}_5=\{R^{Mo}(5,1).R^{smo}(5,0)+R^{sMo}(5,0).R^{mo}(5,1)+R^{Mo}(5,2)\,R^{smo}(5,0)+R^{mo}(5,2)\,R^{sMo}(5,0)\}$$
$$\times!\tfrac{1}{2}\left(2+\frac{5}{5!1}\right)$$
$$+\{R^{Mo}(5,1)\,R^{mo}(5,1)+R^{Mo}(5,2)\,R^{mo}(5,1)+R^{Mo}(5,1)\,R^{mo}(5,2)+R^{Mo}(5,2)\,R^{mo}(5,2)\}$$
$$\times!\tfrac{1}{2}\left(2+\frac{5}{1!1}\right)-N_{5,1}-N_{5,2}$$
$$=\{1.1+1.1+1.1+1.1\}1+\{1.1+1.1+1.1+1.1\}3=16.$$

For $\mathfrak{D}_6$, the partitions of the 6-pyramid, we have the following partitions of the hexgon:—

$$R^{6agdi}(6,0)=1,\ R^{2agdi}:(6,1)=1,\ R^{di}(6,1)=1,$$
$$R^{2agdi}(6,2)=1,\ R^{di}(6,2)=1,\ I(6,2)=1,$$
$$R^{di}(6,3)=1,\ I^2(6,3)=1,$$
$$R^{3di}(6,3)=1;$$

wherefore the formula of XVIII. becomes,

$\mathfrak{D}_6=198$, thus:

$$\mathfrak{D}_6=\{R^{6AcDi}(6,0).R^{di}(6,1+6,2+6,3)+R^{6agdi}(6,0).R^{Di}(6,1+6,2+6,3)\}.!\tfrac{1}{2}\left(2+\frac{6}{6!1}\right) \qquad [=6]$$
$$+\{R^{2AcDi}(6,1+6,2).R^{6agdi}(6,0)+R^{2agdi}(6,1+6,2)\,R^{6AcDi}(6,0)\}.!\tfrac{1}{2}\left(2+\frac{6}{6!2}\right) \qquad [=4]$$
$$+\{R^{2AcDi}(6,1+6,2).R^{di}(6,1+6,2+6,3)+R^{2agdi}(6,1+6,2).R^{Di}(6,1+6,2+6,3)\}.!\tfrac{1}{2}\left(2+\frac{6}{2!1}\right) \qquad [=24]$$
$$+\{R^{2AcDi}(6,1+6,2).R^{2agdi}(6,1+6,2)\}!\tfrac{1}{2}\left(2+\frac{6}{2!2}\right) \qquad [=8]$$
$$+\{R^{Di}(6,1+6,2+6,3).R^{di}(6,1+6,2+6,3)\}\cdot\frac{1}{2}\,\frac{6}{1!1} \qquad [=27]$$
$$+\{R^{6AcDi}(6,0).R^{3di}(6,3)+R^{6agdi}(6,0).R^{3Di}(6,3)\}.!\tfrac{1}{2}\left(2+\frac{6}{6!3}\right) \qquad [=2]$$
$$+\{R^{2AcDi}(6,1+6,2).R^{3di}(6,3)+R^{2agdi}(6,1+6,2).R^{3Di}(6,3)\}.!\tfrac{1}{2}\left(2+\frac{6}{2!3}\right) \qquad [=4]$$
$$+\{R^{Di}(6,1+6,2+6,3).R^{3di}(6,3)+R^{di}(6,1+6,2+6,3).R^{3Di}(6,3)\}\cdot\frac{1}{2}\cdot\frac{6}{1!3} \qquad [=6]$$
$$+R^{3Di}(6,3).R^{3di}(6,3)\cdot\frac{1}{2}\,\frac{6}{3!3}+I(6,2)I(6,2).2\cdot\frac{6}{1!1}+I^2(6,3)I^2(6,3).2\cdot\frac{6}{2!2} \qquad [=19]$$
$$+\{R^{6AcDi}(6,0)I(6,2)+R^{6agdi}(6,0)I(6,2)\}\cdot\frac{6}{6!1} \qquad [=2]$$
$$+\{R^{6AcDi}(6,0)I^2(6,3)+R^{6agdi}(6,0)I^2(6,3)\}\cdot\frac{6}{6!2} \qquad [=2]$$
$$+\{R^{2AcDi}(6,1+6,2)I(6,2)+R^{2agdi}(6,1+6,2).I(6,2)\}\frac{6}{2!1} \qquad [=12]$$
$$+\{R^{2AcDi}(6,1+6,2)I^2(6,3)+R^{2agdi}(6,1+6,2)I^2(6,3)\}\cdot\frac{6}{2!2} \qquad [=12]$$
$$+\{R^{Di}(6,1+6,2+6,3).I(6,2)+R^{di}(6,1+6,2+6,3)I(6,2)\}\cdot\frac{6}{1!1} \qquad [=36]$$

$$+\{R^{3D_1}(6,1+6,2+6,3)I^3(6,3)+R^{3d}(6,1+6,2+6,3).I^3(6,3)\}\cdot\frac{6}{2!1} \qquad [=18]$$

$$+\{R^{3D_1}(6,3)I(6,2)+I(6,2)R^{3d_1}(6,3)\}\frac{6}{3!1}+\{R^{3D_1}(6,3)I^3(6,3)+I^3(6,3).R^{3d_1}(6,3)\}\frac{6}{3!2} \qquad [=6]$$

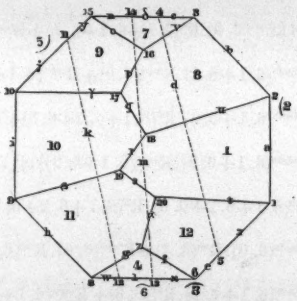
$$+\{I(6,2).I^3(6,3)+I^3(6,3).I\,6,2\}.2\cdot\frac{6}{2!1} \qquad [=12]$$

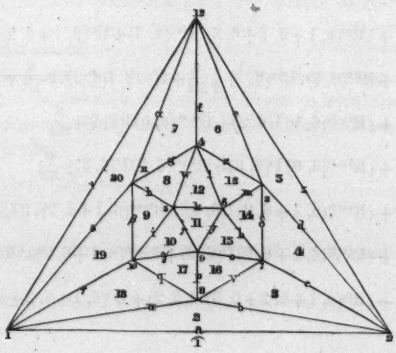
$$-(N\,6,1+N\,6,2+N\,6,3) \qquad [=-2]$$

But I see no advantage that can arise from the construction of these partitions of the 5-based and 6-based pyramids, which is, however, to be effected with the greatest ease.

XXII. It may be worth while to observe, that the regular 12-edron, and of course its polar syntyp the regular 20-edron, are 8-gonous polyedra of the second class. The 12-edron is made by laying a 5-partitioned 8-ace having only two triangular faces on an 8-gon in which four lines are drawn each cutting two edges, and passing through no summit. Two of these cutting lines terminate in the base of each of the triangles just named. This sympolar pair can be exhibited in a paradigm thus; for closed polygons can be drawn through the 20 summits and on the 12 faces of the 12-edron:—

a	*z*	.	.	.	.	.	.	.	.	.	.	*t*
u	*a*	.	.	.	.	.	*b*	.	.	.	.	.
.	*b*	.	.	.	.	*c*	*v*	.	.	.	.	.
.	*c*	*d*	.	.	.	*δ*	.	.	.	.	.	.
.	*d*	*e*	.	.	.	.	.	.	.	.	.	*z*
.	.	*x*	*f*	.	.	.	.	.	.	.	.	*e*
.	.	.	*g*	.	.	.	.	.	.	.	*α*	*f*
.	.	.	*w*	*h*	.	.	.	.	.	.	*g*	.
.	.	.	.	*i*	.	.	.	.	.	*β*	*h*	.
.	.	.	.	*j*	.	.	.	.	*γ*	*i*	.	.
.	.	.	.	*k*	*y*	.	.	*j*	.	.	.	.
.	.	.	*l*	*w*	*k*	.	.	.	.	.	.	.
.	.	*m*	*x*	.	*l*	.	.	.	.	.	.	.
.	.	*δ*	.	.	*m*	*n*	.	.	.	.	.	.
.	.	.	.	.	.	*n*	*o*	.	*y*	.	.	.
.	.	.	.	.	.	.	*v*	*p*	*o*	.	.	.
.	.	.	.	.	.	.	.	*q*	*p*	*γ*	.	.
r	.	.	.	.	.	.	*u*	.	*q*	.	.	.
s	.	.	.	.	.	.	.	.	.	*r*	*β*	.
t	.	.	.	.	.	.	.	.	.	.	*s*	*α*





Here the 30 edges $abc \ldots z\alpha\beta\gamma\delta$ are all 3535, carrying the subindex quadruplets

1 1 2 2,	2 8 3 2,	3 7 4 2,	4 3 5 2,	5 3 6 12,	6 4 7 12,
7 4 8 11,	8 5 9 11,	9 5 10 10,	10 5 11 9,	11 5 12 6,	12 4 13 6,
13 3 14 6,	14 7 15 6,	15 7 16 9,	16 8 17 9,	17 8 18 10,	18 1 19 10,
19 1 20 11,	20 1 1 12,	18 8 2 1,	16 7 3 8,	12 5 8 4,	13 4 6 3,
15 9 11 6,	1 2 5 12,	20 12 7 11,	19 11 9 10,	17 10 10 9,	4 7 14 3.

The closed polygon 123...20 is drawn through the 20 summits, and the closed polygon 123..12 through the 12 faces. If any five continuous edges, of which no three are in a pentagon, be made to convanesce, as the five $\alpha srpq$, the 8-ace is restored, 6 triaces thus uniting to form it. The disappearance of the remaining vanescibles will restore the 8-gon,

Every x-edron of the first class, *i. e.* every partition of a pyramid, can be thus exhibited in a paradigm, and the greater number of those of the higher classes.

The partitions of the r-pyramid have all this property, that each contains a *discrete* r-*gony*, i. e. an r-gonous system of vanescibles of which no diaped meets a diagonal; or each contains an r-gony of the first class. Some of them, however, contain also a *mixed* r-*gony*, on which are one or more angles made by a diaped and a diagonal. If the figure contain a discrete r-gony, it is an r-gonous polyedron of the first class; if not, it is a polyedron of a higher class. The diapeds of a discrete r-gony form a continuous line of convanescibles; if a diagonal be drawn in a face about one of these, the r-gony is no longer discrete, but mixed.

The problems that are next to be solved towards the completion of the theory of the polyedra, are the following; and I have little hope of their solution, in terms of r.

How many partitions can be made of the summits of a partitioned r-gon, so that no $(r+1)$-gon shall be introduced?

How many partitions can be made of the faces of a partitioned r-ace, so that no $(r+1)$-ace shall be introduced?

In how many ways can a partitioned partition of the r-ace be laid on a partitioned partition of the r-gon, so that no $(r+e)$-gony, nor $(r+e)$-gon, or $(r+e)$-ace shall be introduced?

VIII. *On the Isolation of the Radical, Mercuric Methyl.* By George Bowdler Buckton, *Esq., F.R.S.*

Received December 4, 1857,—Read January 7, 1858.

Dr. Frankland, in his memoir communicated to the Royal Society, has described the iodide of an organic base containing mercury, to the hypothetical radical of which he gave the name of hydrargyromethylium. At the same time he pointed out, that in common with zincethyl and analogous bodies, it might be regarded as formed upon the type of the metallic oxides, the oxygen of which, he considered, was represented by methyl, ethyl, &c.

Hydrargyromethylium,

$$C_2H_3\left\{\begin{matrix}Hg\\Hg,\end{matrix}\right.$$

according to this view, corresponds to mercurous oxide,

$$O\left\{\begin{matrix}Hg\\Hg.\end{matrix}\right.$$

Notwithstanding the various ingenious theories advanced with reference to the constitution of these organic metals, the opinion of chemists upon the subject has remained divided; any addition therefore to our knowledge of their decompositions and transformations will be regarded with interest.

Dünhaupt, and more recently Strecker, examined and analysed the salts of hydrargyromethylium and hydrargethylium, but hitherto no successful attempt appears to have been made to convert these bases from the mercurous to the mercuric type.

In an experiment connected with an examination of the nitriles made by Dr. Hofmann and myself, iodide of hydrargyromethylium was acted upon by an aqueous solution of cyanide of potassium, under the impression that cyanide of hydrargyromethylium would be produced. After a digestion for twelve hours in a sealed tube, the chief product consisted of a double salt of iodide and cyanide of the two bases, a compound which readily crystallized in large plates on cooling. The tube also contained an inflammable gas, ammonia, a little reduced mercury, and a few drops of a heavy liquid, which at the time was regarded as regenerated iodide of methyl.

The investigation in this direction was then abandoned, but I have since returned to the subject, with the special view of effecting a partial reduction of the metallic element in the base.

The iodide of hydrargyromethylium was formed in the usual manner by sunlight, in long horizontal tubes, which gave a large surface of mercury for contact with the iodide of methyl. After sufficient exposure, the contents of the tubes were heated to 100° C.

to drive off the iodide of methyl, and the crystalline mass, after separation from the excess of mercury by pressure in a cloth, was powdered and exposed to the air for some hours to remove every trace of iodide of methyl.

This crude mass was generally employed in the following experiments, but the pure compound may be expeditiously obtained by dissolving the crystals in hot aqueous potash. By the addition of weak hydrochloric acid, which must not be in excess, the substance is again precipitated. A subsequent washing in water, in which it is almost insoluble, yields it pure and colourless.

Aqueous cyanide of potassium acts very slowly upon iodide of hydrargyromethylium, and requires a temperature approaching to 200° C. before mercury is reduced.

The volatile matters formed, exert a pressure that few glass tubes can resist, even when assisted by an atmosphere of steam. Much better results were obtained by the following method.

Dry iodide of hydrargyromethylium was rubbed in a mortar with finely divided cyanide of potassium, and distilled in flasks over the naked gas flame.

Small charges and frequent operations are better than acting on large portions. A gas passes with an odour something like that of trimethylamine; also water, ammonia, and finally, a heavy liquid which is not miscible with water. The residue in the flask contains iodide and carbonate of potassium, paracyanogen, and metallic mercury. A portion of iodide of hydrargyromethylium always sublimes.

The distillate was agitated with water, and the lower stratum, which was comparatively small in amount, was twice rectified over chloride of calcium at the temperature of the water-bath.

This liquid has the following properties:—It is colourless, highly refractive to light, and almost wholly insoluble in water. When pure, it has a faint and somewhat sweetish odour, but the crude product is contaminated with the offensive body that always accompanies the decomposition of methyl compounds when heated with cyanide of potassium. The odour may be entirely removed by agitation with very dilute sulphuric acid.

This liquid is very combustible, and burns with a luminous flame and abundant evolution of mercurial vapour. It is soluble in all proportions in alcohol and in ether, from the former of which it is precipitated on addition of water. The vapour detonates loudly when exploded with oxygen gas.

This preparation began to boil at 93°, at which point it remained constant until about $\frac{5}{6}$ths of the whole had passed over; the remainder came over between 93° and 96° C.

The specific gravity of the former portion was found to be 3·069, from which it appears to be the heaviest of known non-metallic liquids. A solid glass rod floats freely on its surface*.

The pure substance contains neither iodine nor cyanogen; still it is very difficult to separate every trace of iodide of hydrargyromethylium which volatilizes with the vapour.

* The specific gravity of bromine at 15° is 2·98. Selenic acid, with one equivalent of water, MITSCHERLICH found to have a density of 2·85.

This impurity is not easily detected until the liquid is burnt with oxide of copper, when a little subiodide of copper generally appears. To this cause is referred the circumstance that the following analyses are slightly below the theoretical value:—

I. 0·9774 grm. burnt with oxide of copper, gave 0·2335 grm. water and 0·3508 grm. carbonic acid.

II. 0·8082 grm. burnt with oxide of copper, gave 0·1895 grm. water and 0·2870 grm. carbonic acid.

III. 0·7800 grm. burnt with soda-lime, gave 0·6718 grm. mercury.

IV. 1·2405 grm. burnt with oxide of copper, gave 1·0680 grm. mercury.

These numbers correspond to the per-centages—

	I.	II.	III.	IV.
Carbon	9·78	9·68	——	——
Hydrogen	2·65	2·60	——	——
Mercury	——	——	86·11	86·09

and accord with the formula

$$C_2 H_3 Hg.$$

	Theory.		Mean of Experiment.
2 equivs. of Carbon . .	12	10·43	9·73
3 equivs. of Hydrogen .	3	2·60	2·63
1 equiv. of Mercury . .	100	86·97	86·10
	115	100·00	

If the materials be dry, the decomposition of iodide of hydrargyromethylium by cyanide of potassium is very simple, and may thus be expressed by equation,—

$$C_2 H_3 Hg_2, I + K Cy = C_2 H_3 Hg + KI + Cy + Hg.$$

I do not find, however, any advantage in using the materials absolutely dry. A little moisture disintegrates the cyanogen, and the resulting gaseous products assist in removing the vapour of the new body from the seat of decomposition.

From the constitution of this compound the name mercuric methyl is proposed. Should this appellation be accepted by chemists, Dr. FRANKLAND's radical would be styled mercurous methyl.

As a corroboration to the foregoing analysis, an experiment was made to ascertain the specific gravity of the vapour, after the method of DUMAS.

	Grammes.	Pressure.	Temperature.
Weight of globe filled with vapour .	10·3245	769 mm.	117° C.
Weight of globe filled with air . .	9·9705	770 mm.	14° C.
Difference = P =	0·3540		

Capacity of the globe = V = 57·0 cubic centimetres.

Volume of mercury entering the globe = 56·5 cubic centimetres.

Difference v = 0·5

$n_{\prime}$ = weight of one cubic inch of air at 14° C. = 0·001230.

$n_{\prime\prime}$ = weight of one cubic inch of air at 117° C. = 0·000905.

By introducing these numerical values into MÜLLER's formula, we have

$$\left.\begin{array}{r}\text{Specific gravity}\\ \text{of the vapour}\end{array}\right\}=\frac{P+Vn_{\prime}}{(V-v)n_{\prime\prime}}=\frac{0{\cdot}42411}{0{\cdot}05113}=8{\cdot}29.$$

The weight represented by the formula C_2H_3Hg, divided by the experimental density, gives the quotient $\frac{115}{8{\cdot}29}=13{\cdot}87$. Supposing the constituents of mercuric methyl condensed into two volumes of vapour, the more accurate number 14·46 should have been obtained.

The theoretical density of the vapour of mercuric methyl is $\frac{115}{14{\cdot}46}=7{\cdot}95$.

Although the salts of mercurous methyl are remarkably stable, the sulphate for instance resisting for some time the action of boiling sulphuric acid, they may be made to part with a portion of their mercury by a variety of means. The action of sodium on mercuric methyl is very slow, and it is only after long boiling that the sodium becomes amalgamated, with the liberation of a gas which is doubtless methyl. The action of sodium, on the other hand, upon iodide of mercurous methyl, is sufficiently great to cause explosion when gently heated. If the sodium be previously amalgamated, and reduced to small pieces, the volatile products will be found to contain a considerable quantity of mercuric methyl. The same decomposition is also effected through lime or hydrate of potassa. A higher temperature appears to be required to induce the change, and accordingly the amount of mercuric methyl obtained is comparatively small.

Marsh-gas is liberated in the decomposition according to the equation

$$2(C_2H_3Hg_2I)+2KO\,HO=C_2H_3Hg+2KI+C_2H_4+3HgO+HO.$$

Decompositions of Mercuric Methyl.

Mercuric methyl exhibits no tendency to unite with the electro-negative elements, such as oxygen and chlorine. All attempts to produce such compounds lead to the destruction of the substance.

Mercuric methyl sinks in concentrated sulphuric acid, and liberates bubbles of a gas which burns with a pale non-luminous flame. This evolution is assisted by a gentle heat.

One volume of this gas, when exploded in the eudiometer with a mixture of oxygen and air, gave, after due correction for pressure and temperature, a contraction equal to two volumes, and subsequently by potash, an absorption equal to one volume of carbonic acid.

This deportment shows the gas to be hydride of methyl or marsh-gas.

After the decomposition of mercuric methyl by an acid, the solution contains an abundance of that salt of mercurous methyl which corresponds to the acid employed.

Thus with hydrochloric acid we obtain the chloride, and with sulphuric acid the sulphate of mercurous methyl,

$$\left.\begin{matrix} C_2H_3Hg \\ C_2H_3Hg \end{matrix}\right\} + HCl = C_2H_3Hg_2Cl + C_2H_3H.$$

On adding bromine to the liquid, a violent action results, and the white and crystalline bromide is formed. Iodine also unites with mercuric methyl with a loud hissing noise. If the reaction be conducted under water, bubbles of gas are disengaged, which prove to be pure methyl gas,

$$\left.\begin{matrix} C_2H_3Hg \\ C_2H_3Hg \end{matrix}\right\} + I = C_2H_3Hg_2I + C_2H_3.$$

The mercury in these bodies is retained with remarkable tenacity, in what may be called organic combination. The strongest acids fail in reducing them to ordinary inorganic mercury salts. They are indifferent also to sulphide of ammonium, at usual pressures and temperatures.

Both compounds are however decomposed, with deposition of mercury, by the action of clean zinc and a dilute acid.

Mercuric methyl is a ready solvent of resins and caoutchouc, but it retains in solution only a small quantity of sulphur even at the boiling heat. The liquid dissolves phosphorus almost in every proportion, but no transformation is effected by subjecting the two bodies to a temperature of 160° C. in a sealed tube.

The solution, when allowed to evaporate on filter paper, leaves the phosphorus in a state so finely divided as to cause spontaneous ignition.

Mercuric methyl furnishes with bichloride of tin a crystalline compound which readily decomposes on the addition of water. Thin colourless plates are formed, which after being well washed with water from the soluble tin salt, were analysed. The crystals were dried over sulphuric acid, and sublimed between watch-glasses.

0·7105 grm. of substance gave with nitrate of silver 0·4090 grm. of chloride of silver. The salt proved therefore to be nothing but chloride of mercurous methyl.

$C_2H_3Hg_2Cl$ requires—

	Theory.	Experiment.
Chlorine	14·18	14·22

An analogous reaction is effected by a similar treatment with terchloride of phosphorus.

Some interest attaches also to the circumstance that mercuric iodide combines directly with mercuric methyl, to form iodide of mercurous methyl.

The change is effected quietly when assisted by a gentle heat.

Mercuric methyl is indifferent to the action of the iodides of lead and silver, the metals most nearly allied to mercury in their general properties.

Mercuric Ethyl.

The foregoing experiments left little doubt of the existence of a corresponding body in the ethyl series. There appears, however, to be some difficulty in obtaining it in quantity, from the ease with which the body undergoes decomposition at a high temperature.

Although little less than one pound of iodide of mercurous ethyl was digested with cyanide of potassium, the distillate obtained was too small in quantity to permit of more than a general examination.

The greater part of the new body is resolved by the heat employed into mercury, paracyanogen, and gaseous matters, of an offensive odour. The product in the receiver was distilled in a water-bath until all iodide of ethyl was driven off. A watery liquid remained having a substratum of an oily consistence, which strongly greased the sides of the retort. At an advanced heat this substance passed over as a colourless, heavy fluid, quite unmiscible with water.

Although unable to obtain an analysis, I have no doubt of this substance being mercuric ethyl. The boiling-point, as before noticed, is above that of water. It burns with a lurid flame, which appears to be smoky from the disengagement of mercurial vapour.

Its behaviour towards acids is just what we might expect from a body so little removed in composition from mercuric methyl. Hydride of ethyl is liberated instead of marsh-gas, as in the former case, and salts of mercurous ethyl are deposited from the acid solutions.

A question now arises as to whether the above-described substances represent, in their respective series, the sole radicals of the organo-mercurial bases.

Up to the present time the radical of mercurous methyl, &c. has not been isolated. Should it indeed exist, its discovery would add weight to GERHARDT's views with reference to the different conditions of mercury, as mercuricum and mercurosum.

I propose to submit to similar treatment the salts of stanethylium and zincethyl. I have already made some preliminary experiments on the former, and the results seem to give promise of subjects of interest.

December 2, 1857.

IX. *Description of the Skull and Teeth of the* Placodus laticeps, OWEN, *with indications of other new Species of* Placodus, *and evidence of the Saurian Nature of that Genus. By Professor* OWEN, *V.P.R.S., Superintendent of the Natural History Departments in the British Museum.*

Received February 6,—Read March 11, 1858.

COUNT MÜNSTER, in the year 1830, obtained two specimens of portions of the upper jaw with the palate and teeth, of a vertebrate fossil, from the Muschelkalk member of the Triassic system near Bayreuth, which he described and figured in a brochure, entitled "Fossile Fischzähne von Bayreuth*," referring the specimens to the class of Fishes. They were chiefly remarkable for the large size, and especially the breadth and shortness, of the crowns of the teeth.

Professor AGASSIZ, in the 'Part' of his great work on Fossil Fishes†, which appeared in 1833, and formed the commencement of the second volume, accepted Count MÜNSTER's determination of the foregoing fossils, referred them to the Pycnodont family of the Ganoid order of his System of Ichthyology, and founded on them a genus which he called *Placodus*, a term significant of the broad flat teeth of such supposed fishes. The generic character given by Professor AGASSIZ is as follows:—"Dents polygones, à angles arrondis, dont la surface est aplatée et entièrement lisse;" and he adds, "Rangé par induction dans l'ordre des Ganoïdes; car je n'ai jamais vu les écailles d'aucun poisson de ce genre?" Of this genus he defines two species:—

1. *Placodus impressus*, AG.; characterized by a depression on the middle of the crown of the tooth, from the triassic formation called 'grès bigarré,' at Deux Ponts.

2. *Placodus gigas*, AG.; characterized by the flat crown of the teeth: from the Muschelkalk, Bayreuth. This species is founded on the specimens originally described by Count MÜNSTER.

Professor BRONN, in his 'Lethæa Geognostica,' adopts the systematic position assigned by Professor AGASSIZ to the genus *Placodus*; but he remarks that it is known by little more than the teeth, which are all short and almost flat, from four- to six-sided, with the angles rounded off; and he states that the vertebral column and scales are unknown. Three species of *Placodus* are admitted in this work‡,—*Placodus impressus*, AGASSIZ, from the Bunter-sandstein of Zweibrücke (Deux Ponts); *Placodus gigas*, AGASSIZ, from the Muschelkalk of Bamberg and Bayreuth; and a third species, afterwards called *Pla-*

* Fossile Fischzähne von Bayreuth, 4to. 1830.

† Recherches sur les Poissons Fossiles, tome ii. 1833–43.

‡ Band i. 8vo, 1837, p. 186. tab. 13. fig. 13.

FRANKLIN INSTITUTE LIBRARY

codus Andriani by AGASSIZ, from the Muschelkalk of Laineck, near Bamberg. In another part of the first volume of the 'Lethæa Geognostica*,' teeth of *Placodus* are cited with those of other Ganoid fishes, in an enumeration of the fossils of the 'Salz-gebirge' (Muschelkalk and Keuper divisions of the Trias).

In 1841 I gave a brief summary, in the section of my 'Odontography' on the teeth of Pycnodonts, of the descriptions of the dentition of *Placodus* from the writings of MÜNSTER, AGASSIZ and BRONN, with a copy of the figure of the teeth of the *Placodus Andriani* given by AGASSIZ. Not having then had the opportunity of examining any original specimens of this singular extinct animal, I adopted, the more readily, the current opinion as to its nature, from the statement by AGASSIZ, that the teeth resembled in microscopic structure those of other Pycnodont genera†.

In 1843 Count MÜNSTER published a description and figure of a considerable part of the facial division of the skull of a *Placodus* from the Muschelkalk of Bayreuth, on which he founded a distinct species, under the name of *Placodus rostratus*‡ (Plate XI. fig. 4). This specimen had the upper part of the cranium imbedded and the palatal surface exposed, showing the marginal teeth and the palatal teeth. The latter are six in number, three on each side (ib. *e, f, g*), in two almost symmetrical series, and demonstrate the absence of any median row of vomerine teeth, such as exists in *Gyrodus* and some other unequivocal pycnodont fishes. The figure of the skull indicates the presence of zygomatic arches, with a curvature and span very difficult to reconcile with the known modifications of the plan of cranial structure proper to the class of Fishes. But it has been only very recently that such specimens of the rare and seemingly peculiarly German triassic fossil have come under my observation, and enabled me to settle the doubts which Count MÜNSTER's figure of *Placodus rostratus* first suggested.

In the meanwhile the essay by HERMAN VON MEYER, entitled "Fossile Fische aus dem Muschelkalk von Jena, Querfurt und Esperstädt," appeared, in the Part (Fünfte Lieferung) of his 'Palæontographica' which was published in 1849. In this essay new localities of the *Placodus* are made known, *e. g.* the Terebratulite limestone (Terebratuliten kalk) of Zwetzen. The prehensile modification of the crown of the anterior teeth of *Placodus gigas* is well illustrated§: the distinct covering of a clear enamel-like substance on the crown of the tooth is mentioned‖; but no suspicion seems to have crossed the mind of this acute and indefatigable palæontologist of any error in the ascription of *Placodus* to the Pycnodont family of Fishes.

In the month of October last (1857) some fossils from German triassic formations were offered for sale to the British Museum, including specimens of *Placodus* from the

* Band i. p. 138.

† "La structure microscopique des dents est la même que chez les autres genres, en sorte que je ne crois pas me tromper en plaçant ce genre aux confines de la famille des Pycnodontes."—AGASSIZ, tom. cit. p. 217.

‡ Beiträge zur Petrifacten-kunde, 4to. Heft 1843, p. 123. fig. 1. taf. 15.

§ Palæontographica, 4to. 1849, tab. 33. fig. 8.

‖ "Der ziemlich stark Schmelz dieser Zahne ist glatt und schwarz, die davon überdeckte Zahnsubstanz weisslich," p. 198.

Muschelkalk near Bayreuth. One of these included a larger proportion of the cranial structure than in any previously known specimen: it also exhibited the upper surface, which in Count MÜNSTER's specimen of *Placodus rostratus* was buried in the matrix, and this surface in the fossil in question, now acquired for the Geological Department of the British Museum (Plates IX. and X. fig. 1), showed the character, viz. the external nostrils (*n*), so surrounded as to be decisive of the genus belonging to an air-breathing class of the Vertebrate series. But, besides the external bony nostrils, the specimen presented the orbits, ib. *o*, with a similar continuous border of bone, together with one of the temporal fossæ, *t*, bounded externally by an arch of bone continued from the post-frontal, 12, to the mastoid, 8; below which was the true zygomatic arch (*ib.* fig. 2) formed by the malar, 26, and squamosal, 27, elements, extending from the upper maxillary, 21, to abut against a short thick but vertically descending tympanic bone, 28. The articular surface for the lower jaw, convex from behind forward, was concave transversely at the middle part between two convexities; this strong trochlear form of joint being unknown in any recent or fossil fish. The bony palate (Plate X. fig. 1) showed the same absence of median vomerine teeth as in Count MÜNSTER's *Placodus rostratus* above referred to; and it also showed a broad pterygoid plate, 24, abutting against the antero-internal side of the fixed tympanic, 29. The sum, therefore, of the characters presented by the skull, as, *e. g.* the nostrils, divided by an ascending process of the premaxillary, 22, and bounded by that bone, the maxillaries, 21, and nasals, 15; the size, shape, and surrounding of the orbits; the magnitude of the temporal fossæ, with their complete double zygomatic outer arches, the condition of the single tympanic bone, and the structure of the bony palate, left no hesitation as to the reference of the genus *Placodus* to the class Reptilia, and herein with nearest affinities to the Lacertian order, and more especially with that modification thereof exemplified by the extinct genus *Simosaurus*, from the Muschelkalk*.

The generic characters of the fossil were unequivocally shown by the shape and relative size of the crowns of the teeth, covered, as in the previously figured specimens, by a black enamel, contrasting strongly with the light grey colour of the fossil bone supporting them. Two slight rectifications of the generic character originally proposed by M. AGASSIZ are necessitated by the subsequent accession of different species. The teeth may present a rounded contour, which is the case in all those of the specimens here described; and the surface of the crown becomes quite smooth only by attrition, the enamel of the newly-risen tooth presenting fine striæ diverging from a central point or fissure. The character on which *Placodus impressus*, AGASSIZ, is differentiated, "une impression ou une sorte de sillon longitudinal qui se voit au milieu de la couronne," is one common to the newly-formed crushing teeth of all *Placodi*.

The species which the specimen under description most nearly resembles in the shape, proportions and arrangement of the teeth, is *Placodus rostratus* of MÜNSTER†: the

* H. v. MEYER, Die Saurier des Muschelkalkes, tab. 20, *Simosaurus Guglielmi*.

† Beyträge, *loc. cit.* Taf. XV. fig. 1 *a* (Plate XI. fig. 4).

specific differences will be pointed out after the description of the teeth as they appear in *Placodus laticeps*.

The teeth of the upper jaw, in this, as in the other known species of *Placodus*, consist of an external or maxillary series (Plate X. fig. 1, *a*—*e*), and an internal or palatal series, ib. *f*, *g*. The maxillary series are supported in a marginal row of alveoli by the premaxillary and maxillary bones: the palatal series appear to be implanted in the palatine and pterygoid bones.

The maxillo-premaxillary teeth are five in number on each side, two, *a* and *b*, implanted in the premaxillary, and three, *c*, *d* and *e*, in the maxillary. The premaxillary teeth are subequal, smaller than the maxillary teeth; their crowns are subhemispheric, that of the first being 4 lines, that of the second 3 lines in diameter: the enamel is worn off from the back or inner side of the crown, showing that the lower jaw was shorter than the upper one. On the inner side of the right premaxillary teeth the crown of a small successional tooth has begun to protrude from the bone: it presents rather strong irregular rugæ diverging from a small central pit: this character has been worn away from the crowns of the teeth in place. The premaxillary teeth, in proportion to their breadth, are longer or project further from their sockets than the other teeth; but none of them present the bent, pointed, prehensile character of the incisive tooth figured in tab. 70, fig. 21 of the 'Recherches sur les Poissons Fossiles,' and referred by AGASSIZ to *Placodus gigas*.

The maxillary part of the marginal series is not continued directly from the premaxillary row, but begins on a plane internal to it, by the breadth of the second premaxillary tooth, *b*. From this point the three maxillary teeth extend outward and backward in a line parallel with that formed by the premaxillary teeth.

The first maxillary tooth, *c*, has a full oval crown, $4\frac{1}{2}$ lines by 4 in diameter. The second maxillary tooth, *d*, measures $5\frac{1}{2}$ lines by $4\frac{1}{2}$ lines in diameter: the longer axis in both teeth is in the line of the series. The third maxillary tooth, *e*, is subcircular, 8 lines in diameter, on the right side; but on the left side the transverse diameter is 9 lines, the other diameter the same as the left tooth.

The palatal series begins on the inner side of this tooth, and consists of two teeth on each side.

The first tooth, *f*, apparently developed in the true palatine bone, ∞, has a full elliptical crown, 10 lines by 8 lines: the second tooth, *g*, developed in the broad pterygoid bone, presents a full oval shape, 1 inch 9 lines by 1 inch 3 lines in diameter. The longer axis of both teeth is in the line of the series, and this line is on nearly the same parallel—from within outward and backward—as the premaxillary and maxillary rows. The last large tooth is slightly hollowed, by attrition, at the middle of the grinding surface; the primitive radiating striæ of the enamel are visible only round the margin and sides of the tooth.

All these teeth are implanted by short simple bases in distinct shallow sockets, according to the 'thecodont' type of dentition in the Lacertian order. Evidence has already

been given of their being subject to the same law of displacement and succession as in other reptiles; but this is common to both reptiles and fishes.

The total number of teeth in place in the upper jaw of *Placodus laticeps* is fourteen.

In *Placodus rostratus* (Plate XI. fig. 4), as in *Pl. Münsteri*, *Pl. Andriani*, and *Pl. gigas*, the internal or palatal teeth are six in number, three on each side. In *Pl. rostratus* and *Pl. Münsteri*, the first two palatal teeth are subequal and much smaller than the last great tooth: they are situated on the inner side of the last two maxillary teeth in *Pl. Münsteri*; but are both posterior to the maxillary series in *Pl. rostratus*.

In *Placodus gigas* and *Pl. Andriani*, the palatal teeth (called 'vomerine' by MÜNSTER and 'internal' by AGASSIZ), three in number on each side, are all of large size, slightly increasing from before backward; they are situated close together, forming on each side a series a little curved with the convexity outward, and the interspace between the two series is very narrow. The first tooth is triangular, the second and third are quadrangular; each with the angles rounded, and the transverse diameter exceeding the fore and aft or longitudinal one. The maxillary teeth are much smaller than the palatal ones; have a rounded or subquadrate crown; are four in number; and of subequal dimensions: the series is somewhat curved, with the convexity next the outer alveolar margin; commencing a little in advance of the first palatal tooth, and terminating opposite the interspace between the penultimate and last palatal teeth. The premaxillary teeth, three in number on each side, are more remote and distinct from the maxillary teeth than in *Placodus rostratus* and *Pl. laticeps*. They form an almost transverse series at the fore-part of the upper jaw; and their crowns are more elongated and conical than in *Pl. laticeps*; the prehensile power of the prolonged premaxillary part of the jaw being obviously greater in *Placodus gigas* than in *Pl. laticeps* or *Pl. rostratus*. The size of the last tooth in *Pl. laticeps* surpasses that of any of the teeth in the previously discovered species. In proportion to the entire skull, it is the largest grinding tooth in the animal kingdom, that of the Elephant itself not excepted.

The specific distinction of the fossil exhibiting the true reptilian characters of the genus, and for which I propose the name *Placodus laticeps*, is satisfactorily established by the dental distinctions pointed out in the foregoing comparisons. By some systematists it may even be deemed requisite to separate generically the *Placodi* with two teeth, from those with three teeth, in each palatal series: but *Placodus rostratus* offers a transitional condition in the small relative size of the first two palatal teeth, and in the rounded form of all the teeth, from *Pl. Andriani* to *Pl. laticeps*; and I do not perceive any advantage that would compensate for an additional generic term in the present state of knowledge of the Placodont reptiles.

The chief distinctive feature of the cranium of *Placodus laticeps*, is the great proportional size of the temporal fossæ and wide span of the zygomatic arches. The great muscular force applied to work the jaws and their crushing machinery adequately is indicated by this modification. The breadth of the skull at this part equals, at least,

the length, and imparts a triangular form to the whole, viewed from above or below. The name *laticeps* was suggested by this character; but it would apply almost as well to *Placodus rostratus* and *Pl. Münsteri*. In *Pl. Andriani* and *Pl. gigas*, the length of the skull plainly exceeds the breadth.

The apex of the triangle is formed by the premaxillary (Plate IX. fig. 1, 22); it is rounded off: the outer surface of the premaxillary is smooth, and the convex border projects a little way beyond the alveoli of the teeth. It is a single bone sending upward and backward a median process which meets and articulates with the nasals (*ib.* 13), and so forms the partition between the external nostrils.

These orifices (Plate IX. *n*, figs. 1 and 2) are of an oval form with the small end forward, rather sharply defined above, but with the lower border rounding off into the floor of the passage below; about 9 lines by 6 lines in the two diameters. The suture between the premaxillary and maxillary begins about the middle of the lower border of the nostril; that between the premaxillary and nasal is behind the middle of the upper border: the hinder border is formed by the nasal above, by the maxillary below, and by a bar of bone half an inch in breadth, which divides the nasal from the orbital cavity; whether any or what proportion of a lacrymal bone enters into the formation of this bar, the sutural traces are too obscure to enable me to determine. The alveolar border of the maxillary (*ib.* fig. 2, 21), containing the three teeth, *c*, *d*, *e*, forms a slight convex curve downward; then slightly rises and bends rapidly outward to pass into the malar portion of the zygomatic arch, 26. The orbit (Plate IX. *o*, figs. 1 and 2) is subcircular, 14 lines in longitudinal, by 12 lines in vertical, diameter: like the nostril, the upper boundary is sharply defined; the lower border rounds in to the floor of the cavity; the front border shows a middle prominence, low and broad, which contracts as it extends back upon the floor of the orbit.

The interorbital space on the summit of the cranium is slightly convex both across and lengthwise; its breadth is 7 lines, a little increasing backward.

The bony wall of the face below the orbit expands rapidly and spreads outward as it extends backward, dividing about 1⅓ inch behind the orbit into the upper and lower zygomata. It is by analogy that I conclude these zygomata, which are peculiar to certain Sauria and a few birds, to be composed—the upper one of the conjoined postfrontal and mastoid, the lower one of the malar and squamosal elements. Both zygomata, in *Placodus*, arch outward with a span peculiar for its extent and convexity, the lower arch curving outward by more than its own breadth beyond the upper one. This arch is about half an inch in breadth, its flat surface looking almost directly upward; the margins turned inward and outward: the former is sharply defined. The lower or proper zygoma was evidently of greater breadth than appears in the specimen, for its outer border has been broken away: had it been entire, the breadth of this remarkable skull would have been even greater than it now is. The temporal fossa (*ib.* fig. 1, *t*), circumscribed by the upper zygoma externally, and by the proper cranial parietes internally, is an ellipse, 3 inches in the long diameter, which is in the axis of the skull, and 2 inches

across. The blow which severed the portion of rock, containing the fossil, extended obliquely from behind the right orbit to the back part of the left temporal fossa, and destroyed the upper wall of the cranium proper. The facial part of the skull thus preserved, including the nostrils and orbits, gives the direction of the mid-line of the skull, and demonstrates the reptilian contraction of the cranial cavity; which appears to have measured only an inch across at the middle of the temporal fossæ. The total breadth of the skull here exceeded 8 inches; the total length being somewhat under 8 inches. The small degree of height of the skull, fig. 2, contrasts strongly with these dimensions, especially with the breadth. The vertical diameter of the skull between the orbits is $1\frac{1}{2}$ inch: from the very gradual slope from this part to the end of the mouth, it would seem that the height of the cranium was not greatly increased as it extended backward. The occipital portion of the skull is wanting; and the structure of the base of the skull cannot be satisfactorily made out; the bone and matrix are so blended on the palate and so nearly alike in tint. I believe the inner nostrils to have opened between the two series of maxillary teeth: the matrix can be traced uninterruptedly from the outer nostrils downward and a little backward to this part of the palate: the pterygoid part of the palate behind the last great tooth is $3\frac{1}{2}$ inches across, slightly arched, with the outer angles abutting against the short and thick tympanic, the structure of which has been already described.

For the purposes of future comparison the following dimensions (English, and French metrical) are added to those mentioned in the text:—

			Placodus laticeps.
	in.	lines.	French.
From the first premaxillary to the last pterygoid tooth, in a straight line, including both teeth	4	4	0·11
Extent of the two premaxillary teeth	0	9	0·018
Extent of the three maxillary teeth	1	8	0·042
Extent of the two palato-pterygoid teeth	2	9	0·07
Breadth between the hindmost premaxillary teeth, including those teeth	1	5	0·035
Breadth between the hindmost maxillary teeth, including those teeth	3	1	0·08
Breadth between the hindmost pterygoid teeth, including those teeth	3	6	0·09
Breadth of trochlear articular surface of the tympanic	1	3	0·03
From the fore-end of the skull to the back part of the tympanic	6	10	0·175
From the fore-end of the skull to the fore-part of the external nostril	0	9	0·018
From the fore-end of the skull to the fore-part of the orbit	2	2	0·05
From the fore-end of the skull to the fore-part of the temporal fossa	3	6	0·09
From the outer margin of one nostril to that of the other	1	3	0·03
From the outer margin of one orbit to that of the other	2	10	0·073
Breadth of the skull across the back part of the nostrils	2	4	0·055
Breadth of the skull across the back part of the orbits	6	3	0·158

(The latter admeasurement gives the peculiarly rapid expansion of the facial part of the skull.)

In the German members of the Trias, from which remains of *Placodus* have been obtained, other well-marked forms of the Reptilian class have been discovered, including

the labyrinthodont *Reptilia*, with genera of lacertian affinities, for the knowledge of which we are chiefly indebted to M. HERMAN V. MEYER*.

Nothosaurus, *Simosaurus* and *Pistosaurus*, present the same evidences of lacertian affinities in the division of the nostrils by the median extension of the premaxillary backward to the nasals, the same thecodont dentition, and the same circumscription of the orbits and temporal fossæ as in *Placodus*: there is also a general family likeness in the upward aspect of these apertures, accompanying an extreme depression of the skull. The muzzle, though varying greatly in length in these genera, presents the same obtuseness; and the alveolar border of the jaws the same smooth outward convexity which we observe in the *Placodus*. The peculiar confluence of the elements of the upper and lower zygomatic arches, *i. e.* of postfrontal and malar, forming the broad wall of bone behind the orbit, is continued still further backward in *Simosaurus*†. In *Pistosaurus*, the elongated postfrontal, malar and squamosal are united together in one deep zygomatic arch, which has the mastoid and tympanic for its hinder abutment. The lower articular surface of the tympanic bone presents the same trochlear form in *Pistosaurus* and *Simosaurus* as in *Placodus*‡.

The dentition of the triassic Saurians described by v. MEYER, although, like *Placodus*, thecodont in respect of implantation, is of the ordinary lacertian or crocodilian type in respect of form, the crown of every tooth being long and sharp-pointed, adapted to the prehension of fishes or other active vertebrate animals: moreover, they are developed, as in Crocodiles and Enaliosaurs, exclusively in the premaxillary, maxillary and mandibular bones, the palatal bones being edentulous. Besides, however, the instances in modern lacertian genera of palatal teeth, the triassic Labyrinthodonts also exhibit the same superaddition, and the unequal magnitude of some of these teeth may be noticed as presenting an analogy with the dentition of *Placodus*.

Fig. 1.

nat. size.

Dentine and Enamel, *Placodus laticeps*.

The structure of the teeth of *Placodus*, like that in *Nothosaurus* and *Simosaurus*, conforms to the ordinary crocodilian and lacertian type. The dentine (fig. 1, *d*) is of the hard unvascular kind, and the crown of the tooth is covered by a moderately thick well-defined layer of true enamel (fig. 1, *e*). This enamel, in the newly-formed tooth, presents numerous, close-set, fine irregular striæ or rugæ, radiating from a central groove or pit on the summit: the teeth are subject to the same succession and displacement as in the *Reptilia* generally.

* Die Saurier des Muschelkalkes. Fol. 1847–1855.

† Ib. tab. 20. fig. 1, and tab. 65. fig. 2.

‡ Tab. 21. fig. 3.

The dentine presents, under an adequate magnifying power, extremely fine, numerous and close-set dentinal tubuli, without admixture of medullary canals: they radiate from the wide and shallow pulp-cavity, with a corresponding feeble divergence, at right angles to the outer surface of the tooth. The tubuli are, at first, straight; but show two slight primary bends near the periphery of the tooth. They present a diameter of $\frac{1}{20,000}$th of an inch, with interspaces varying between two and three times that diameter; they divide once or twice in their course: a few secondary branches were discernible near the periphery of the dentine. The difference between this dentinal structure and that of true pycnodont fishes is seen in the larger relative size and much closer arrangement of the dentinal tubuli in those fishes, and their apparent composition of a closely twisted bundle of smaller tubes, owing to the oblique direction and number of the branches sent off into the intertubular substance*. The terminal branches into which the tubuli resolve themselves penetrate, in Pycnodonts, the clear substance which is analogous to enamel, but is a continuation and slight modification of the intertubular or basement tissue of the entire tooth. In *Placodus* the layer of enamel (fig. 1 *e*) is as distinct as in the Monitor or Crocodile. It is a very dense and compact substance, in which a structure of fibres, vertical to the surface, is but faintly discernible near the dentine.

The osseous tissue of *Placodus* (fig. 2) exhibits concentric layers around the Haversian canals, the area of one of which is shown in fig. 2. The lacunæ or bone-cells, of a size and shape closely resembling those of the Plesiosaurus and Crocodile, have diverging tubuli larger than in Mammals, with a more wavy course and fewer ramifications. The tubuli are much more numerous in the best-preserved and prepared slices of bone than in the specimen figured; which shows, however, the characteristic reptilian size and irregular or subangular contour of the bone-cell.

Fig. 2.

Osseous tissue of jaw, *Placodus laticeps*.

We cannot contemplate the extreme and peculiar modification of form of the teeth in the genus *Placodus* without a recognition of their adaptation to the pounding and crushing of hard substances, and a suspicion that the association of the fossils with shell-clad mollusks in such multitudes as to have suggested special denominations to the strata containing *Placodus* (*e. g.* Muschelkalk, Terebratulitenkalk, &c.), is indicative of the class whence the *Placodi* derived their chief subsistence.

No doubt, the most numerous examples of similarly-shaped teeth for a like purpose are afforded by the class of Fishes, as, *e. g.*, by the extinct Pycnodonts, and by the Wolf-fish (*Anarrhichas lupus*) and the Cestracion of the existing seas. But the Reptilian class is not without its instances at the present day of teeth shaped like paving-stones, of which certain Australian lizards exhibit this peculiarity in so marked a degree that the generic name *Cyclodus* has been invented to express that peculiarity†. Amongst extinct Reptiles, also, a species of lizard from the tertiary deposits of the Limagne, in

* See 'Odontography,' pl. 33.

† Ibid. pl. 66. fig. 7.

France, presents round obtuse teeth, of which the last, in the lower jaw, is suddenly and considerably larger than the rest *.

Mandible, or lower jaw.—Count MÜNSTER obtained from the Muschelkalk of Bayreuth a portion of one ramus of a lower jaw with three teeth in place, which M. AGASSIZ has figured in tab. 70, figs. 15 and 16, of his great work on Fossil Fishes †; referring it to *Placodus gigas*. From this specimen M. AGASSIZ concludes that there was but one row of teeth in each ramus of the jaw ‡. The three teeth in place are of large size and subquadrate form: a fourth smaller tooth appears on the surface of the bone, at a lower level. This M. AGASSIZ considers an incisor; but certain appearances in the specimens, presently to be described, lead me to regard it as a successional anterior molar, exposed in its formative cavity by fracture or abrasion of the bone at that part. M. AGASSIZ, indeed, remarks on the peculiarity of its implantation in the outer border of the jaw §. Its crown is obtuse, and of half the size of the foremost of the three teeth in place.

There is no character adduced in the text or plate in proof of the piscine affinities of the above fossil jaw.

Four specimens of portions of lower jaw form part of the collection of Muschelkalk fossils from Bayreuth, in addition to the cranium of the *Placodus laticeps*, now acquired by the British Museum.

The first of these mandibular specimens (Plate X. figs. 6 and 7), includes part of the left ramus and a smaller portion of the right ramus united by the hinder portion of the symphysis, *s*, *s*. In the left ramus the first (*a*) and third (*c*) teeth are preserved, in the right ramus the first (*a*) and second (*b*) of the three large subquadrate teeth which are figured in the mandibular fossil described by M. AGASSIZ.

These teeth are somewhat smaller in the present specimen and are differently shaped. The grinding surface of the last (fig. 7 *c*) is almost a complete square with the angles rounded off, measuring 1 inch in length, and 1 inch $\frac{1}{2}$ a line in breadth; the inner border is one line longer than the outer border. In the *Placodus gigas* the corresponding tooth is 1 inch $2\frac{1}{2}$ lines in length, and 1 inch 3 lines in breadth: the inner border is 4 lines longer than the outer one, and the angles are more rounded off than in the present specimen. The second (penultimate) tooth in the present specimen (fig. 7, *b*) resembles in shape the last: the length and breadth are each 11 lines. In *Placodus gigas* the corresponding tooth is notably broader than it is long, and the inner border is longer than the outer one. The first tooth on each side, in the specimen under description

* GERVAIS, Zoologie et Paléontologie Françaises, pl. 64, figs. 5–7.

† Recherches sur les Poissons Fossiles, 4to. tom. ii.

‡ "Il est évident d'après cela, que chaque branche de la mâchoire n'avait qu'une rangée de larges molaires, et que les rangées externes manquaient complètement."—Recherches sur les Poissons Fossiles, 4to. tom. ii. p. 219.

§ "Ce que est remarquable, c'est que cette dent soit implantée en quelque sorte au borde externe de la mâchoire," ib. p. 219.

(figs. 6, 7, *a*), is a successional one, not having risen into place, and with the crown showing the fine radiating irregular rugæ: its breadth much exceeds its length, being as 10½ lines to 6½ lines, and the latter dimension is along the inner border, which is double the extent of the outer rounded border; the grinding surface is rather triangular than quadrate. In *Placodus gigas* the corresponding tooth does not present such a disproportion between the outer and inner borders, but preserves more of the transversely extended quadrate form. By the comparison of the above three principal crushing teeth of the lower jaw, therefore, the fossil under consideration is specifically distinct from *Pl. gigas*. It may belong to the species called *Placodus Andriani*; but, if distinct, it is most probable that the three close-set, large, broad and flat-crowned teeth were opposed to three similarly shaped and aggregate teeth, such as are seen in *Placodus gigas* and *Placodus Andriani*.

In the specimen (Plate X. figs. 6 and 7), the symphysis (*s*, *s*) has been broken across immediately in front of the first of the three teeth: its breadth at this part is 2 inches 3 lines; its depth is 10 lines. The rami of the jaw, after they become free, expand in depth, retaining a breadth or thickness of 1½ inch; are flattened or broadly rounded below; are thus of peculiar massiveness and strength, adapted to the support of the large crushing teeth; and the rami diverge at an open angle which relates to the characteristic breadth of the skull in the *Placodi*. Only the dentary elements are preserved; the alveolar border extends 4 lines beyond the last of the grinding teeth, forming a flat ledge of that breadth; the corresponding projection in the larger mandible of *Placodus gigas* is of about half the breadth. The inner border of the last tooth almost overhangs the vertical inner wall of the ramus. The symphysis seems to have developed a low median ridge along its under surface.

It is possible that the specimen here described may be part of the under jaw of a *Placodus Andriani*; but, as the two other mandibular rami next to be described have the same claims to such relationship from the size and form of the grinding teeth, and one of them an additional claim through a structure of the jaw-bone, I am induced to indicate the species presenting the peculiarly thick, massive proportions of the mandibular rami above described, as *Placodus pachygnathus*.

The specimen (Plate IX. figs. 3, 4, 5 and 6), is the middle portion of the left ramus of the mandible, with the last three large grinding teeth *in situ*: it consists of the dentary element, showing the same angular notch in the vertically extended back part which may be observed in *Nothosaurus* and other Muschelkalk Saurians*. The upper border of the dentary in *Nothosaurus* rises behind the last tooth into a low analogue of the coronoid process, and a similar modification exists in the present mandible, and obviously to a greater extent, but the summit of the process is broken off; the fore-part of its base is continued, as in *Placodus gigas* and *Pl. pachygnathus*, forward upon a ledge of bone outside the alveoli of the last two teeth: the breadth of this ledge is equal to that in *Pl. gigas*†.

* H. v. Meyer, Die Saurier des Muschelkalkes, tab. 3. fig. 2. † Agassiz, tom. cit. tab. 70. fig. 16

The three grinding teeth are relatively much smaller, as the following dimensions show:—

	Pl. gigas. in.	lines.	*Pl. bombidens.* in.	lines.
Vertical diameter of the jaw behind the last tooth . . .	1	3	1	9
Antero-posterior extent of the three grinding teeth . . .	2	9	2	2
Antero-posterior extent of the last grinding tooth . . .	1	2½	0	10
Antero-posterior extent of the middle grinding tooth . .	0	10½	0	7½
Transverse extent of middle grinding tooth	0	14	0	10
Antero-posterior extent of first grinding tooth	0	7½	0	6
Transverse extent of first grinding tooth	0	11⅔	0	9

The inner half of the last tooth of *Placodus bombidens* (Plate IX. fig. 5, *c*) is broken away, but its relatively smaller dimensions in the remaining part are decisive against its specific identity with the *Pl. gigas*.

The crown of the penultimate grinder (figs. 3, 4 and 5, *b*) is peculiar for its great degree of convexity, especially in the transverse direction. The median transverse furrow from which the rugæ of the enamel have radiated is still discernible on the worn crown, as are the rugæ themselves on the inner part of the crown.

Beneath the anterior tooth, *a*, the crown of its successor, *a'*, is exposed in figs. 4 and 6, the enamelled summit of which is complete; it is of the same size as the tooth it is about to displace, and this is important in estimating the value of dental characters in regard to difference of size. For, had the present fossil belonged to a young animal, not fully grown, the successional teeth would probably have been larger than their predecessors; or if, as in the case of most fishes, growth of body had continued throughout life, some indication of a maintenance of proportion with augmenting general bulk might have been expected in the successional teeth. I conclude, therefore, that we have in the portion of jaw here described, a part of a full-grown animal of its species, and that the dental characters exhibited are specific.

The mandible begins in advance of the first grinding tooth to bend a little outward, and this indicates an expansion of the fore or symphysial part of the jaw, analogous to that of the premaxillary part of the jaw in *Placodus Andriani**. The fore-part of the angular element of the jaw appears below the back part of the dentary, to which it articulates by suture; and here the under part of the angular shows a sutural surface for the splenial element, indicative that this element appeared in a slight degree upon the outer surface of the ramus.

All these indications of the compound structure of the mandible concur with the characters of that part in *Nothosaurus* and some other triassic Saurians.

It is very probable that the fossil just described may belong to the species called *Placodus Andriani*. Provisionally it has been entered under that name in the 'Catalogue of the British Museum Series of Fossils.' Should ulterior acquisitions prove it to belong

* Agassiz, tom. cit. tab. 70. fig. 8.

to a different species, the term *bombidens* would best express what seems to be the specific peculiarity in the shape of the surface of the grinding teeth.

The third portion of the lower jaw (Plate XI. figs. 1, 2 and 3) differs from both of the last described, and from that of *Placodus gigas*, in the absence of any ledge outside the last molar tooth; the outer alveolar wall of which, as well as that of the next tooth, descends sheer upon the outer surface of the ramus.

The present specimen is chiefly instructive for the extent and height of the coronoid process, 29′, and for the additional evidence it yields of the compound structure of the mandibular ramus.

The angular element, 30, is preserved for an extent of nearly 4 inches behind the last molar tooth: the osseous substance is plainly traceable in the matrix midway between the tooth and the broken angle of the jaw, so as to give a vertical extent of 3½ inches to this part of the ramus, which much resembles in general shape what is called the ascending ramus of the jaw of a carnivorous quadruped. At its upper half the outer surface is flat, the lower half is convex, and this undulates by a slight concavity as it extends forward into the again convex outer surface of the horizontal ramus supporting the teeth. The fore-part of the angular piece, 30, is wedged between the dentary, 28, and splenial, 31; the surangular, 29, is interposed between the angular and the upper and back part of the dentary, 29′: the summit of the coronoid process appears to be contributed by the surangular. The joint-part of the articular element seems to be accidentally lost; it was not brought out in the extent to which the matrix could be safely removed from the present specimen. The concave inner surface of the angular element, 30, and the suture between it and what I take to be the fore-part of the surangular element, 29, are well shown. The inner plate of the splenial has been removed: the articular surface for the splenial element, and a vascular longitudinal groove which that element would have covered, are exposed on the inside of the dentary part of the horizontal ramus.

In this part of the jaw two teeth—the last (*c*) and penultimate (*b*) grinders—are in place: both are of subquadrate form, and in this respect, as well as size, resemble the same teeth in *Placodus pachygnathus*, from which species, however, the present much differs in the shape of the jaw.

The last tooth (*c*, fig. 2) has been but recently acquired; the rugæ being obliterated from only a small proportion of the middle of the crown, where there is a depression of a somewhat crucial figure. This tooth measures 1 inch along the inner border, and the same across the crown; the outer border is 9½ lines in extent.

The next tooth (*b*, fig. 2) has been worn smooth and flat; its outer part is broken away; the extent of its inner border is 10 lines; its breadth 11 lines. Beneath it on the surface of the dentary, left uncovered by the missing splenial piece, the inner side of the enamelled crown of a successional tooth (*b′*, fig. 3) is exposed. The inner border of the crown of both teeth a little overhangs the inner wall of the jaw.

The development of the parts of this compound jaw for the attachment of muscle

harmonizes with the expanse of the temporal fossa and the size of the zygomatic arch, and with the force required for the due working of the extraordinary teeth which are developed in it.

The depth of the ramus behind the last molar is 1 inch 10 lines.

It may be concluded, from the size and shape of the two molars in place in the present jaw, that it belonged to a species which, like *Placodus gigas* and *Pl. Andriani*, had similarly-proportioned teeth in the upper jaw, and not to species in which, as in *Pl. rostratus* and *Pl. laticeps*, the last tooth is considerably larger than the one in front of it. From *Placodus pachygnathus* it differs, not only in the absence of the ledge outside the last tooth, but by the commencement of the symphysis in advance of the second tooth. The species which it indicates may be named *Placodus bathygnathus*.

The last fragment of a *Placodus* from the Muschelkalk of Bayreuth, which will be here noticed, is a small portion of jaw containing three teeth (Plate X. figs. 2, 3, 4 and 5). These are subequal, and, as compared with those last described, of small size: in this respect, as in their shape, they correspond with the marginal teeth of the upper jaw of *Placodus gigas*.

The bone is preserved on one side only, and for the extent of about an inch, gradually thinning off into the mass of matrix which chiefly constitutes the specimen.

If this free bony surface belongs, as I surmise, to the upper and outer part of the upper jaw, the crowns of the teeth project further beyond the free outer alveolar margin, as in fig. 4, than they appear to do in the figure of the upper jaw of *Placodus gigas*, in the 'Poissons Fossiles' of M. Agassiz. At the same time, the crown and working surface of the crowns of the teeth look downward, as they ought to do on the above supposition of the natural aspect of the exposed surface of the bone.

On making a vertical section of one of the three teeth *in situ* (fig. 5), a cavity of reserve, *f*, was exposed above and on the inner side of the tooth in place, containing half of the crown of a successional tooth, *d*, with the well-defined enamel contrasting with the dentine.

Herman v. Meyer, the historian of the extinct Saurians of the continental Muschelkalk, has made us familiar, by means of his exact descriptions and beautiful figures*, with the genera *Nothosaurus*, *Pistosaurus* and *Simosaurus*, the precursors and near allies of the long-necked *Plesiosauri* of a subsequent mesozoic age.

The evidence which has been adduced in the foregoing pages establishes, I trust, an addition to this series, of a Saurian genus, unique in its order for the singularity of its dentition. It is remarkable that, hitherto, no vertebræ or other bones of the trunk or limbs have been found so associated with the teeth of *Placodus*, as to have suggested their belonging to the same species. Usually, after the indication of a reptile by detached teeth, the next step in its reconstruction is based upon detached vertebræ. The twelve or more evidences of *Placodus*, afforded by bone as well as tooth, are all portions of the skull.

* Die Saurier des Muschelkalkes. Fol. 1847–55.

It is possible that some of the singularly modified vertebræ from the Muschelkalk, indicated by v. MEYER under the generic name of *Tanistropheus**, and the family one of *Macrotracheliens*†, may belong to the *Placodus*; and the same surmise suggests itself in reference to some of the limb-bones from the Muschelkalk that cannot be assigned to other known Saurian genera. I shall be amply repaid if the present labour which has been devoted to the rectification of the class affinities of the *Placodus*, should tend to accelerate the acquisition of fossils further advancing our knowledge of its Reptilian structure.

The obvious adaptation of the dentition of *Placodus* to the crushing of very hard kinds of food, its close analogy to the dentition of certain fishes known to subsist by breaking the shells of whelks and other shell-clad Mollusks, and the characteristic abundance of fossil shells in the strata to which the remains of *Placodus* are peculiar, concur in producing the belief that the species of this genus were reptiles frequenting the sea-shore, and probably good swimmers‡. But as, at present, we have got no further than the head and teeth in the reconstruction of this mesozoic form of conchivorous Reptile, I will conclude with a remark suggested by the disposition and form of the teeth. In all the species, under the rather wide range of specific varieties of the dentition, there are two rows of the crushing teeth in the upper jaw, and only one row in the lower jaw, on each side of the mouth; and the lower row plays upon both upper rows, with its strongest (middle) line of force directed against their interspace. Thus the crushing force below presses upon a part between the two planes or points of resistance above, on the same principle as that by which we break a stick across the knee; only here the fulcrum is at the intermediate point, the moving powers at the two parts grasped by the hands. It is obvious, that a portion of shell pressed between two opposite flat surfaces might resist the strongest bite, but subjected to alternate points of pressure its fracture would be facilitated.

DESCRIPTION OF THE PLATES.

PLATE IX.

Fig. 1. Upper surface of the skull of *Placodus laticeps*, OWEN.

Fig. 2. Side view of the same skull.

Fig. 3. Outside view of part of the lower jaw of *Placodus bombidens*, OWEN.

Fig. 4. Inside view of the same jaw of *Placodus bombidens*, showing a successional tooth.

Fig. 5. Upper view of the same jaw of *Placodus bombidens*.

Fig. 6. End view of the same jaw of *Placodus bombidens*, showing the formative cavity of the successional tooth, *a'*.

* Die Saurier des Muschelkalkes. Fol. 1847–55, pp. 42, 128. † Ibid. p. 165.

‡ The *Nothosaurus* and some other reptiles of the Muschelkalk seem to have had limbs resembling the paddles of the *Plesiosauri*.—H. v. MEYER, *op. cit.* p. 33.

PLATE X.

Fig. 1. Under view of the skull, with the dentition, of *Placodus laticeps*.

Fig. 2. Inner view of a portion of the upper jaw, with three marginal teeth, of *Placodus gigas*, AGASSIZ.

Fig. 3. Grinding surface of the same teeth.

Fig. 4. Outer view of the same portion of jaw and teeth.

Fig. 5. Section of a tooth and part of the jaw of the same specimen, exposing a formative cavity, *f*, with a successional tooth, *d*.

Fig. 6. Portion of mandible, with teeth, of *Placodus pachygnathus*, OWEN.

Fig. 7. Upper view of the teeth in the same fossil.

PLATE XI.

Fig. 1. Outside view of a part of the mandible and teeth of *Placodus bathygnathus*, OWEN.

Fig. 2. Grinding surface of last and penultimate tooth of *Placodus bathygnathus*.

Fig. 3. Inside view of the dentigerous part of the mandible of *Placodus bathygnathus*, exposing part of a formative cavity and tooth-germ, *b'*.

Fig. 4. Under view of the skull, with the dentition, of *Placodus rostratus* (MÜNSTER, 'Petrifacten-kunde,' taf. 15).

All the figures are of the natural size: they were not reversed in the drawing, so that the 'right' in the text and specimens is the 'left' in the plates.

X. *On the Properties of Electro-deposited Antimony.* By G. Gore, *Esq.* *Communicated by Dr.* Tyndall, *F.R.S.*

Received December 10,—Read December 10, 1857.

1. While engaged in depositing antimony by the electro-process in October 1854, I observed a remarkable phenomenon of development of heat in the deposited metal when gently struck, and published a brief account of it in the Philosophical Magazine for January 1855; since that period I have investigated the phenomenon, and have now the honour of laying the results before the Royal Society.

2. In depositing this metal by the electro-process several solutions may be successfully used, consisting of compounds of the metal either with hydrochloric or tartaric acid; but those I have generally operated with have consisted,—1st, of ordinary chloride of antimony (as prepared for pharmaceutical purposes) nearly saturated with antimony, by suspending a plate of that metal in it as an anode, and passing an electric current from several pairs of zinc and silver batteries through it until a copious deposit of *bright* metal occurred, and until its yellow colour had nearly disappeared; and 2nd, of five parts of tartar-emetic and five parts of tartaric acid, dissolved in a mixture of two parts of hydrochloric acid and thirty parts of water; each solution being filtered before using. A most excellent solution in lieu of the first may quickly be formed by saturating ordinary chloride of antimony with tartar-emetic, using about three or four parts of the former to one of the latter; or by dissolving two parts of tartar-emetic in three parts of hydrochloric acid. I have also in place of that liquid occasionally used hydrochloric acid saturated with antimony by the battery process; and sometimes a liquid composed of seven parts of tartar-emetic dissolved in a mixture of eight parts of hydrochloric acid and four parts of water. Substituting pure acid, distilled water, and pure antimony, for those of the ordinary quality, made no material difference in the results. Each solution requires to be electrolysed a short time before it yields a good and uniform deposit.

3. There are two distinct kinds of antimony deposit produced in these liquids, which I shall distinguish by the terms *amorphous* and *crystalline*; *dark* and *grey*: for the special production of the former I use the first liquid, or better that composed of chloride of antimony and tartar-emetic; and for the latter I use the second: the first solution will yield both varieties, but the second gives the crystalline variety alone. The line of demarcation between the two kinds of deposit is rigorously distinct, and there appears to be no transitional or intermediate gradation, at least not by this mode of procedure.

4. There are a great many circumstances which influence the production of those two

kinds of metal in the first liquid; but the most important are, the temperature and density of the solution, the strength of the battery, the state of the depositing liquid, and the physical condition of the receiving surface; if the battery is nearly exhausted in power, the solution unequal in density from long-continued working and neglected stirring, and the receiving surface rough or unclean, the deposited metal will be amorphous and smooth in the lower and denser part of the liquid, and crystalline and warty in the upper and lighter portion. If the liquid is boiling hot, or if it is very dilute or contains much free acid, the deposit will be grey throughout.

5. The production of either of these deposits is so easy that the simplest of conditions will suffice. To produce the amorphous variety, take a small battery consisting of one or two pairs of zinc and platinized silver plates, charged with a mixture of one measure of sulphuric acid and twenty measures of water, and having prepared a small quantity of the mixture of chloride of antimony and tartar-emetic, connect with the terminal silver a piece of commercial antimony ("best French regulus") of the same amount of immersed surface as one of the battery-plates, and immerse it in the liquid as an anode, and for a receiving surface immerse a piece of clean polished silver or copper of about one-half the amount of surface of the antimony; connect it by a silver or copper wire with the negative pole of the battery; suspend it vertically in the lower part of the depositing liquid at a few inches from the anode, and protect the connecting wire from receiving a deposit near the surface of the liquid by a piece of gutta-percha tube, glass tube, or by a layer of varnish formed by dissolving pure gutta percha in bisulphide of carbon to the consistence of treacle. A perfectly bright deposit of amorphous antimony will immediately be formed, and will, if the electric power is rather great, exhibit a scaly surface after half an hour's action; but by further continuance the scaliness will cease, and a firm coherent deposit of perfect brightness, and of similar appearance to highly polished steel, will be produced. If the electric power is too great, the deposit will be granular and loose. Much impure matter will appear upon the anode during the process, especially if "common bowl regulus" is used, and may be removed by means of a hard brush and dilute hydrochloric acid. There is no depositing liquid with which I am acquainted, of any metal, which will bear so great a variation of electric power without deteriorating the quality of the deposit, as that composed of tartar-emetic dissolved to saturation in hydrochlorate of terchloride of antimony; good amorphous deposits have been obtained in it with batteries varying from one to thirty-six pairs in intensity.

6. To produce a crystalline deposit, prepare a similar quantity of the second liquid, and proceed in exactly the same manner, except that a much larger receiving surface should be used in consequence of the greater tendency to a sandy deposit; and the protecting tube or varnish may be omitted. In this case the deposit is grey, and frequently of a dull aspect, or even a dark loose granular powder if the power is too great; but when properly produced it has a silky lustre or semi-iridescent silver-grey appearance, especially when viewed within the liquid; and if the process is continued several days,

or better for one week, the edges of the deposit assume a partly nodular form. The cleaning of the anode in this case may be of less frequency, and with water alone.

7. A speed of deposition, varying from 0·75 to 3·0 grains per square inch of receiving surface per hour, has repeatedly yielded a good bright deposit with the first-named solution; and from 0·25 to 2·25 grains per square inch per hour has often given a good crystalline deposit with the second liquid. By keeping the cathodes in constant motion, much more rapid action may be successfully ventured.

8. By similar means to those described, and without the aid of motion, a solid bar of dark bright antimony, upwards of 1 inch in diameter and 3 inches long, was formed upon a piece of copper wire $\frac{1}{10}$th of an inch thick and 2 inches long, in a period of twenty-eight days, and with the aid of motion in about half that time.

9. In depositing antimony from these solutions a variety of circumstances occur, a knowledge of which will greatly assist in obtaining perfect specimens of the two varieties. In using the ordinary chloride, after the process has been progressing one or two days with continuous bright deposit, warty excrescences of the grey variety will nearly always occur upon portions of the receiving surface, the localities of their appearance differing according to the shape of the cathode and its depth of immersion; if it be within half an inch of the surface of the liquid, rough grey metal will appear upon its upper parts. The presence of these excrescences appears in nearly all cases to depend upon accumulations of partly exhausted solution at the upper part of the liquid, and at different parts of the receiving surface. The solution, partly deprived of its metal by the action, and thus rendered specifically lighter, ascends in a layer against the cathode, and accumulates at its over-hanging parts and at the surface of the liquid, and yields in those exhausted or acid portions only the grey deposit; similar effects, but in a much less degree, occur in the solution of chloride of antimony and tartar-emetic. To obviate these effects, the solution should be frequently stirred; and to entirely prevent them, the cathode should be immersed at least 1 inch below the surface of the liquid, and be kept in a constant state of gentle swinging motion by attachment to the moving pallets of an ordinary clock. Roughness or want of cleanliness of the receiving surface also seems to favour the production of those excrescences.

10. On every occasion with the first liquid, when the battery power became nearly exhausted grey nodules appeared, and when once commenced there was a strong tendency in them to continue; but by increased electric power, stirring the liquid, and persistent action, they became covered with amorphous deposit.

11. If during the process of deposition the temperature of the first solution was gradually raised, the deposited metal suddenly changed from amorphous to crystalline at about 205° Fahr., and less suddenly resumed its amorphous character on cooling at about 79° Fahr.; on interposing a galvanometer the conductivity of the circuit was found to be gradually increased during the rise of temperature, and gradually decreased during the fall. These phenomena were repeatedly produced by reheating the same portion of liquid; and similar effects were obtained with the solution composed of

tartar-emetic and dilute hydrochloric acid. The first liquid exhibited no material irregularity in its rate of cooling, indicative of molecular change, between 220° and 100° FAHR. By previously evaporating the same solution to one-half its original bulk, its tendency to yield a grey deposit by heat was considerably reduced; and by diluting it either with pyroxylic spirit, dilute hydrochloric acid, or solution of table-salt, its aptitude to give grey metal at ordinary temperatures was increased and its depositing quality injured.

12. Upon examining the electric relations of the depositing liquids with platinum plates in the apparatus described at page 1 of the Philosophical Magazine, January 1857, hot platinum was found to be increasingly electro-negative to cold platinum up to 210° FAHR. in the tartaric acid solution, in accordance with the general rule there stated; but with the first liquid an unusual variation occurred, hot platinum being increasingly negative to cold platinum up to 110° FAHR., then decreasingly to 145° FAHR., and above that temperature increasingly positive to 210° FAHR. Similar effects were obtained with small square columns of DUBOSCQ's carbon (made by him for electric light apparatus) immersed in those liquids in V-tubes. In each case the solution was previously boiled, and repeated experiments gave uniform results.

13. By separating the first and second solutions from each other by means of a porous diaphragm, and immersing two perfectly similar pieces, either of platinum or of DUBOSCQ's carbon, one in each liquid, and connecting them with a galvanometer, that in the chloride solution was in each case found to be rather strongly electro-positive to that in the tartaric acid liquid.

14. In depositing from either of the solutions which yield the *amorphous* metal, especially ordinary chloride of antimony nearly saturated with antimony by the battery process, there is a great tendency in the deposit to extend itself in the form of a thin sheet of grey metal upon the surface of the liquid; this lateral spread of the metal is unique, and increases rapidly, and like the grey excrescences formed upon other parts of an amorphous deposit, its speed of increase is much greater than that of the dark metal near it (see 10.); the reason of this appears to be that crystalline antimony is more electro-negative than the amorphous variety, and therefore receives the electric current with greater facility. I have found with perfect specimens of grey and dark antimony deposited upon perfectly similar copper wires, that the amorphous variety was electro-positive to the crystalline in the following liquids:—dilute phosphoric, sulphuric, hydrochloric, and nitric acids; in aqueous solutions of ammonia, potash, and carbonate of soda; also in the first-mentioned chloride solution. This difference of electric condition was in some instances of deposition so great as to generate a separate electric current, and completely redissolve some of the dark portions. The phenomenon of lateral surface deposit did not occur in the tartaric acid solution. Antimony trees, consisting of branches of amorphous and crystalline nodules, were easily formed by suspending a horizontal copper wire as a cathode upon the surface of the terchloride solution.

15. Heat was perceptibly evolved in the first-named liquid during deposition; on one

occasion with a feeble battery, when the external air was at 66° FAHR., the coldest part of the liquid, viz. behind the anode, was at 67°·5 FAHR., and the warmest part in front of the anode 71° FAHR. And on another occasion, with a stronger battery, consisting of twenty-four pairs of zinc and silver plates, weakly excited, with an anode of moderate size, a thermometer in contact with the front of the anode rose from 74°·5 to 87°·5 FAHR.

16. Faint crackling sounds, audible at about 4 or 5 feet distant, frequently occurred in the depositing liquid during the process; they issued from the receiving surface, and appeared to be due to alterations in the cohesive state of the metal, being generally attended by the production of cracks, and occasionally of complete rents in the metal; they most frequently occurred when the temperature of the deposit was changed by removal from the liquid or by reimmersion. In one instance metallic sounds were definitely traced to bubbles of gas suddenly expelled with force from a small spot of a very firm deposit formed upon a bar-magnet in the tartaric acid liquid, but no fissure or orifice was observable at the part; they were unattended by evolution of light.

17. In common with electro-deposits generally, the inner and outer surfaces of these deposits are in unequal states of cohesive tension, frequently in so great a degree as to rend the metal extensively and raise it from the receiving surface during the process in the form of a curved sheet with its concave side towards the anode. This separation is very apt to occur in depositing upon extended flat surfaces, and does not often occur when the form of the surface is unfavourable, as with wires, rods, bars, &c., where the deposit extends around the mass, or where it passes round projections, edges, &c., and retains a hold thereby. This state of tension is most manifest in thin deposits, and especially in the first-formed layer; for by depositing a thin layer of amorphous antimony upon gold-leaf attached by varnish to a tube of glass, the film of gold was quickly raised from the surface, and curled into fantastic shapes by the cohesive action. Both varieties of the metal exhibit this phenomenon.

18. The fracture of amorphous antimony is conchoidal, smooth, and wavy; that of the grey variety is crystalline, radiating like hematite. The texture of the former is rather soft and weak, that of the latter is quite hard and strong. The amorphous metal files easily, the grey with more difficulty. The grey metal, if struck by a hard substance, emits a clear metallic sound, whilst the dark variety gives a more dull tone. The crystallization lines of grey antimony are at right angles to the receiving surface; and in several experiments of depositing upon magnets, the direction of those lines did not seem to be altered by the magnetism.

19. The amorphous variety, if gently struck by a hard substance, undergoes *a rapid and intense change* throughout its mass, attended by development of considerable heat; the crystalline kind undergoes no such change, apparently under any circumstances. The change appears to be molecular in its character; and according to this view the crystalline variety of metal must be regarded as being in a state of comparatively stable molecular equilibrium.

20. The following are a few selected instances of this phenomenon. Antimony was

deposited to $\frac{1}{10}$th of an inch thick upon a permanent bar-magnet immersed vertically in the solution of tartar-emetic and dilute hydrochloric acid; the deposit was well washed, and after remaining in this state two days, I struck it gently with a small piece of iron; it at once shattered all to pieces with great evolution of heat and with a small cloud of vapour, emitting an odour of burnt tartrates and hydrochloric acid.

21. On another occasion a deposit $\frac{1}{8}$th of an inch thick formed upon one side of a copper medallion in the same liquid had been removed from the solution and lain in water thirty-six hours, I then wiped it dry and momentarily applied the flame of a candle to a very small portion of its edge; the whole at once changed with exceedingly great evolution of heat.

22. Once having by accident feebly struck a deposited bar $\frac{5}{8}$ths of an inch thick against the glass containing vessel beneath the surface of the liquid, the metal was immediately shattered throughout; many pieces fell to the bottom of the vessel, and a powerful suppressed bubbling noise as of heated metal plunged into water occurred.

23. At another time, when examining the thermo-electric properties of a bar $4\frac{1}{2}$ inches long and $1\frac{1}{4}$ inch thick, on bringing a heated brass wire near to a very small portion of one end of the bar, a sudden change or commotion of particles took place throughout the mass, passing rapidly from the heated part to the opposite end, attended by the production of a few very minute cracks, and with great evolution of heat, rapidly boiling a few drops of water placed upon it.

24. And on another occasion, on accidentally touching a cathode covered with perfect amorphous deposit against the anode, the change with considerable hissing noise occurred, the electric spark or current from the battery being in this case the apparent exciting cause of the phenomenon.

25. And finally, with a rapidly formed and perfect specimen of dark antimony deposited upon a swinging helix of fine copper wire, on washing it first in dilute hydrochloric acid and then in water, and gently striking it with a piece of glass, it at once shattered into small particles with considerable force, projecting some of them to a distance of 10 feet, apparently by converting into steam the adhering particles of water.

26. This thermic property of amorphous antimony is retained apparently unimpaired upwards of $2\frac{1}{2}$ years; a piece deposited in October 1854 evolved considerable heat by slight percussion in May 1857. The change appears to be similar to the molecular changes of sulphur, selenium, iodide of mercury, &c., observed by RITTORF, REGNAULT, WEBER, and others. I have never found that the phenomenon could be repeated with the same specimen.

27. The only observed exciting causes of the phenomenon have been ordinary heat, concentrated solar heat, friction, percussion, fracture, and the voltaic spark. Heat appears *always* to determine it, whilst with thin deposits, slight percussion and even fracture have frequently failed. Thick pieces will bear gentle filing, but not violent fracture at ordinary temperatures without the change occurring.

28. The production of the change and the rapidity of its action are considerably dependent upon the temperature of the mass; pieces which would easily fracture without further change in cold water would not break without change in the air at 60° FAHR.; the certainty and quickness of the action were also manifestly greater when the metal had been previously warmed.

29. Immersing the metal in water and gradually heating it to 212° FAHR. did not cause the change, destroy the property, or have any material effect upon the rate of heating of the liquid. Nor did sudden immersion in boiling water, or partial dissolving of the metal by warm aqua-regia, cause it, or destroy the property; but slight percussion on removing it from the hot water caused it powerfully.

30. At the suggestion of Mr. FARADAY, and with the kind assistance of him and Dr. TYNDALL, I have been enabled to reduce pieces of the metal of moderate thickness ($\frac{1}{10}$th of an inch) to a state of fine division without exciting the change or destroying the thermic property, by carefully triturating them in a mixture of broken ice and salt. Pieces of the thickness of an address card were reduced to powder without the change occurring by careful pulverization in water at 60° FAHR.; the most ready plan adopted was by gently pressing the pieces in small quantity, under water, in a mortar with a rolling motion of the pestle (not by blows or rubbing) until they attained the size of a pin's head, listening all the time to detect molecular changes, then reducing the particles to complete powder by gentle rubbing.

31. By placing small quantities of the dried active powder upon thin sheets of metal and gradually applying heat until the change occurred, sufficient heat was evolved by the molecular force to commence oxidation, which spread at a much lower speed throughout the mass, producing true combustion, and raising it to a temperature of dull redness visible in daylight. The molecular change in the powder is attended by a visible commotion amongst the particles. Portions of the grey variety reduced to powder and treated similarly, exhibited the same combustion.

32. It would appear from these experiments that amorphous antimony is susceptible of three different, distinct, and independent changes:—1st, the cohesive change of its mass, consisting of extensive fractures and bending; 2nd, the peculiar change, attended by evolution of heat; and 3rd, a chemical change, consisting of *oxidation and true combustion*; whilst the crystalline variety is susceptible of only two of these changes. Antimony, deposited in the state of a black powder upon a small cathode, by rapid action in the solution of tartar-emetic and chloride of antimony, exhibited no perceptible change of the second kind, but manifested rapid combustion by application of heat; and similarly with antimony powder, deposited from a solution of antimonic oxide in pyrophosphate of soda. Deposits of metal, obtained from solutions of tersulphide of antimony in caustic potash, exhibited the phenomenon of unequal cohesion, but not the peculiar change. Fused terchloride of antimony, free from water, with an anode of antimony and cathode of copper, did not conduct, even in a small degree, the electric current from five pairs of zinc and silver batteries. By rotating a horizontal silvered

disc of thin brass, $1\frac{1}{4}$ inch diameter, in the solution of tartar-emetic and chloride of antimony, at a speed of 3500 revolutions per minute for thirty-three minutes, and simultaneously passing a current from five zinc and silver batteries through it by means of a disc of antimony $2\frac{1}{4}$ inches diameter, a scaly deposit of bright black metal was obtained, possessing the usual thermic property.

33. In every case where the deposited metal was dark and shining, it evolved heat by the exciting causes, and under the conditions named; and in every case where it was grey and crystalline, it would not evolve heat.

34. The physical properties of the metal appear to be closely connected with the condition of the liquid; for in every case where the latter was sufficiently changed, whether by alteration of chemical composition, of density, of temperature, or of the electric power, a change occurred in the colour and brightness of the deposit; at the same time, by experimentally examining the influence of each of these circumstances separately, I did not find the peculiar state of the metal to be invariably connected with any one of them.

35. On immersing a piece of the unchanged metal in mercury, and applying heat very gradually, it suddenly changed with great force at a temperature of about 250° Fahr.

36. A deposit, consisting of 279·5 grains of amorphous antimony and 101·5 grains of the grey variety, was formed upon a spherical bulb of a thermometer, and after well washing and drying, was wrapped in cotton-wool and touched with a small heated wire; it at once changed, and the mercury rose from 75°·2 Fahr. to 275°·2 Fahr. in twenty-eight seconds. The diameter of the glass bulb was $\frac{15}{32}$ of an inch.

37. A second deposit, consisting of 504·49 grains of dark antimony, formed upon the same bulb, and treated in a similar manner, raised the temperature of the mercury from 75° Fahr. to 445°·0 Fahr. in one minute forty seconds. The thickness of the layer of metal was $\frac{1}{4}$th of an inch, and by the great heat evolved it acquired a dull grey aspect, similar to the grey variety.

38. A cylindrical bar of the amorphous metal, about $\frac{1}{2}$ an inch in diameter, formed upon a rod of grain tin $\frac{1}{8}$th of an inch thick, when changed by the momentary application of a heated wire, evolved sufficient heat to melt the tin completely, which ran out through a crack in the antimony, and remained fluid a short time. A bar of bismuth, $\frac{3}{16}$ths of an inch thick, coated to about $\frac{3}{4}$ths of an inch in diameter, did not melt by the change.

39. By immersing a perfect bar of the dark variety, weighing 456·9 grains, in 836·6 grains of distilled water, contained in a large thin glass tube wrapped in cotton-wool, immersing the bulb of a thermometer in the water, and allowing the whole to acquire a uniform temperature, then inducing the change by momentary contact of a heated wire, and stirring the water to render it uniform, the temperature of the water rose from 63° to 82° Fahr. The cooling influence of the water, in this and in several similar experiments, appeared to prevent the metal undergoing its full amount of change.

40. The peculiar change is attended by alterations in the colour and fracture of the metal; from a bright steel colour and glassy fracture, it passes to a dull grey colour and granular fracture, as if it progressed a stage towards the crystalline modification: this is particularly manifest in thick pieces gradually heated in the air until the change occurs. It is also attended by a change in the form of the metal; bars which were nearly straight before the action, were considerably curved afterwards, and the direction of the curvature was such, that the outer side, or that last deposited, invariably became more concave. Upon applying heat to a thin layer of dark antimony, formed upon a thin sheet of silver, it immediately underwent the change, and became exceedingly curved in a similar direction. This direction of curvature appears to be due to a cause already mentioned (see 16. 17), the unequal cohesion of the inner and outer surfaces of the metal.

41. By applying heat to the ends of deposits formed upon heliacal copper wires, the action was gradually propagated to the opposite ends at a speed varying from 12 to 30 feet per minute; and its rapidity of progress appeared to be dependent upon the temperature of the metal and the cooling influence of the enclosed wire, also upon the absence of grey nodules; the warmer the antimony, the greater its thickness, and the more free it was from grey metal, the more rapid was the action; and in cases where the deposit was thin in places, or had occasional grey nodules, the action was impeded at those parts, and sometimes totally arrested. Grey nodules invariably impeded the action, and caused it to progress by sudden starts. The progress of the change was rendered more or less visible by the evolution of a cloud of vapour at its advancing point; also in the case of fine copper wires, by a peculiar snake-like movement in the coils at that part, apparently produced by the cohesive alteration already mentioned (see 16. 17. 40.). After the change, the layer of antimony contained numerous transverse and longitudinal fissures, as if it had contracted in those directions.

42. In a number of instances, by connecting the ends of the copper wires with a galvanometer, and inducing the change in the coating by a heated wire, a feeble electric current occurred in the enclosed wire whenever, from thinness of the coating, its termination, or other causes, the action ceased; and in every case passed in a direction opposite to that of the peculiar action. By touching the deposit with a heated wire some time afterwards at the point where the action ceased, a current of ordinary thermo-electricity was in each case generated, and passed in a similar direction.

43. By exciting the peculiar change in two pieces, weighing upwards of 600 grains each, placed in the vicinity of the poles of delicately suspended magnetic needles, no deflection of the latter in either case occurred.

44. By taking two bars, each about 3 inches long, one of amorphous antimony and one of the crystalline variety, connecting their extremities with a galvanometer, and cautiously bringing a small flame of a spirit-lamp within half an inch of their remote and touching ends, the dark bar was found to be feebly thermo-electro-positive to the grey one. A thin rod of changed antimony was found, in a second experiment, to be weakly

thermo-positive to a large lump of grey metal. And in a third trial, a large changed bar was positive to a bar formed by melting and casting deposited antimony.

45. Both the grey, the changed, and the unchanged metal acquired a coating of dendritic crystals of silver by immersion in a solution of nitrate of silver.

46. The following are some determinations of the specific gravity of the deposits:—

Three specimens of unchanged antimony.	Five bars of unchanged antimony.
No. 1. 5·739 at 70° FAHR.	No. 4. 5·766 at 60° FAHR.
No. 2. 5·924 at 62° FAHR.	No. 5. 5·769 at 62° FAHR.
No. 3. 5·944 at 62° FAHR.	No. 6. 5·782 at 62° FAHR.
	No. 7. 5·785 at 62°·5 FAHR.
	No. 8. 5·814 at 61°·5 FAHR.

The bar No. 4 weighed 467·00 grains; and by immersing it in 750 grains of distilled water at 60° FAHR. and inducing the change, it evolved a little chloride of antimony, and acquired a density of 5·818 at 60° FAHR. The bar No. 7 weighed 456·9 grains, and by changing it in 836·6 grains of water at 63° FAHR. (see 39.), it acquired a density of 5·862 at 62°·3 FAHR. And the bar No. 8, changed in the air, acquired a density of 6·186 at 61°·5 FAHR.

Four specimens of changed antimony.	Ten specimens of grey antimony.
No. 1. 5·748 at 75° FAHR.	No. 1. 6·369 at 75° FAHR.
No. 2. 5·818 at 60° FAHR.	No. 2. 6·444 at 72° FAHR.
No. 3. 5·880 at 62°·5 FAHR.	No. 3. 6·497 at 72° FAHR.
No. 4. 6·029 at 64° FAHR.	No. 4. 6·522 at 75° FAHR.
	No. 5. 6·557 at 75° FAHR.
	No. 6. 6·616 at 72° FAHR.
	No. 7. 6·616 at 75° FAHR.
	No. 8. 6·662 at 75° FAHR.
	No. 9. 6·671 at 75° FAHR.
	No. 10. 6·673 at 75° FAHR.

Nos. 1 and 2 of the grey specimens were deposited from the upper part of the solution, composed of tartar-emetic and dilute hydrochloric acid; the remainder were deposited from the tartaric acid liquid, Nos. 9 and 10 being formed very slowly. The greater specific gravity of the crystalline metal appears worthy of consideration in connexion with similar differences of density of amorphous and crystalline sulphide of antimony*.

47. The densities of both varieties changed to that of ordinary antimony by fusion; several specimens were fused under tersulphide of antimony, also under cyanide of potassium, and their specific gravities were as follows:—6·67; 6·694; 6·71 at 76° FAHR.; 6·75 at 73° FAHR.; and 6·83 at 75° FAHR.

48. I have endeavoured to determine the electro-chemical equivalent, or equivalents,

* Vide GMELIN's Handbook, vol. iv. p. 337–349. Cavendish Society.

of the two deposits; and by repeated experiments with two perfectly similar batteries, one for depositing the metal, and the other for determining the loss of zinc by ordinary chemical action, and deducting the average loss of zinc in the cells of the idle battery from that occurring in those of the working one, and excluding, as far as possible, all other sources of error, I found in one experiment that for every 32·6 parts of zinc dissolved, 43·38 parts of amorphous antimony were deposited in the solution of tartar-emetic and dilute hydrochloric acid; in a second experiment 43·61 parts of antimony were deposited; and in a third experiment 43·71 parts; and of grey antimony, from the tartaric acid solution, 41·1 parts.

To exclude the possibility of difference of local action in the two batteries, I arranged three depositing liquids in succession, viz. 1st, the saturated solution of chloride of antimony (*i. e.* saturated with antimony by means of a battery); 2nd, a solution composed of 4 parts of sulphate of copper, dissolved in a mixture of 1 part of pure sulphuric acid and 20 parts of distilled water; and 3rd, the tartaric acid solution of tartar-emetic. A current from twelve pairs of zinc and silver batteries was passed through these liquids by suitable electrodes of copper and antimony, and the weights of the respective deposits, after washing and drying, ascertained; and I found in the following experiments that for 31·7 parts of copper deposited in the sulphate solution, the weight of perfect crystalline deposit varied from 40·41 to 40·797 parts, and of perfect amorphous deposit, from 42·304 to 43·813 parts.

Crystalline deposit.		Amorphous deposit.	
No. 1.	40·41 parts.	No. 1.	42·304 parts.
No. 2.	40·612 parts.	No. 2.	43·112 parts.
A No. 3.	40·659 parts.	No. 3.	43·160 parts.
B No. 4.	40·707 parts.	A No. 4.	43·170 parts.
No. 5.	40·797 parts.	No. 5.	43·199 parts.
		B No. 6.	43·428 parts.
		No. 7.	43·813 parts.

Nos. 3 of grey deposit, and 4 of amorphous deposit, were formed by the same current; and Nos. 4 of grey and 6 of amorphous deposit, were also formed by one current. Nos. 1 of grey, and 3 and 7 of amorphous deposit, were formed upon copper wire helices, kept in a state of constant motion; No. 7 being formed by very slow action.

49. In a separate experiment, with a two-pairs battery, the equivalent of crystalline metal obtained was 40·728, and of amorphous metal 43·989; and in a very reliable experiment with a moving helix, the equivalent obtained of amorphous antimony was 43·284. With a one-pair battery, an equivalent of 44·95 parts of amorphous metal was obtained.

50. One source of variation in the resulting numbers of the dark variety appeared to arise from particles of the depositing liquid being mechanically enclosed within the depositing metal, chiefly by the formation of minute cracks and scales; these were, as far as possible, prevented by using cathodes formed of wire, maintaining a uniform tem-

perature and an uninterrupted electric current, by suitable adaptation of the electric power, and by keeping the cathodes in constant motion. The adhering liquid was removed by washing in dilute hydrochloric acid, distilled water, and drying.

51. The amorphous metal invariably contained a small portion of chloride of antimony, more or less of which was always evolved during the molecular change, according to the temperature to which it was raised; thin pieces, changed under water, still retained the greater portion of the chloride. A thin specimen, formed upon a copper wire helix, lost by change in air 0·337 per cent. of its weight, and a thick one lost 3·556 per cent. The grey variety, when perfectly prepared, evolved scarcely a perceptible odour of burnt tartrates or hydrochloric acid by the application of heat.

52. To remove the chloride of antimony, portions of thin deposits were finely pulverized in cold water, then washed either with distilled water, dilute hydrochloric acid, or solution of caustic potash, finally with water and dried; small quantities of the chloride were removed, especially by the dilute acid, but in each case the powder still retained its thermic property, and evolved chloride of antimony during the change. Other portions of the pulverized metal were shaken with boiling hot dilute hydrochloric acid, also boiled in similar acid; the chloride was then found to be more completely removed, and the thermic property destroyed. By digesting the powder in one part of hydrochloric acid and three parts of water, for one week, less chloride was evolved during the change and during the combustion succeeding it.

53. A solid piece of amorphous antimony, weighing 774·0 grains, was placed under a bell-glass filled with water, and the change induced in it by a blow; a small quantity of chloride of antimony separated, together with a minute quantity (less than $\frac{1}{20}$th of a cubic inch) of gas; the water was then strongly acidulated with hydrochloric acid, and allowed to rest five days; the gas still remained unabsorbed.

54. By fusing well-washed specimens, either of the grey or of the changed dark variety, perfectly free from laminæ or crevices, in a porcelain crucible, no material alteration occurred in them until at a temperature of incipient fusion; they then swelled to a large pasty mass, evolving volatile matter, and finally contracted to a clear shining globule, covered with downy crystals of oxide of antimony. Similar results were obtained by fusion under tersulphide of antimony or cyanide of potassium, except that in the latter case a minute quantity of black matter separated, which I found by combustion alone, and with nitrate and chlorate of potash, to be carbon. The metal, previously powdered and placed under cyanide of potassium, agglutinated into a pasty mass before fusion or evolution of vapour. Five specimens of grey antimony, fused under the cyanide, lost respectively 0·437, 0·618, 0·81, and 0·88 per cent. by weight. Two thin specimens of amorphous antimony, previously changed under water at 60° Fahr., lost respectively, by fusion under cyanide of potassium, 5·1 and 5·2 per cent. A moderately thin specimen, previously changed in air at 60° Fahr., lost 3·3 per cent.; a thick one, similarly changed, lost 2·1 per cent.; a second ditto lost 2·52 per cent.; and three other specimens of changed antimony lost respectively 3·484, 3·92, and 5·56 per cent. Two

specimens of antimony, $\frac{1}{10}$th of an inch thick, changed in the air at 60° FAHR., and then fused under chloride of potassium, lost each 7·0 per cent. by the fusion, while two other portions of the same lost, by fusion under cyanide of potassium, 1·86 and 2·1 per cent. respectively. Five pounds of the changed dark metal, fused in an ordinary crucible, evolved much volatile matter at complete fusion. The antimony, fused under cyanide of potassium, and cooled slowly without disturbance, had strong crystalline markings upon its upper surface, while that fused under chloride of potassium had not, probably because in the latter case the salt solidified before the metal and confined its surface.

55. The combined loss of weight by the change, and by fusion under cyanide of potassium, of three specimens, was as follows:—first specimen, a thin one, changed in air at 65°·0 FAHR., lost 3·31; by fusion, 2·49; total loss, 5·8 per cent.: second specimen, a thin one, by change in air, 3·19; by fusion, 2·71; total loss, 5·9 per cent.: and third specimen, deposited at the upper part of the liquid, by change in air, 1·94; by fusion, 3·098; total loss, 5·038 per cent.

56. Small pieces, either of grey or changed antimony, immersed in fused nitrate of potash, rose to the surface by the aid of the evolved gas when approaching fusion, and burned with great evolution of heat and formation of antimoniate of potash. No particular effect occurred by rubbing together unchanged antimony powder and pulverized chlorate of potash.

57. Contrast of the two varieties:—

Unchanged dark variety.	Grey variety.
Specific gravity: 5·739 to 5·944.	Specific gravity: 6·369 to 6·673.
Colour: *Polished steel.*	Colour: *Silver-grey.*
Fracture: *Amorphous.*	Fracture: *Crystalline.*
Texture: *Soft and weak.*	Texture: *Hard and strong.*
Relative electric condition: *Positive.*	Relative electric condition: *Negative.*
Relative thermo-electric state: *Positive.*	Relative thermo-electric state: *Negative.*

58. It would be interesting to inquire, to what force or mode of physical action is the evolution of heat in antimony due? If it is caused by some *new* mode of physical action, then the force causing it will of course differ, in some respects, from all other forces, and will be found to manifest itself in a number of substances and not in antimony alone, like heat, electricity, magnetism, &c.; and will also be found, like each of them, to be correlative with, and convertible into, other natural forces.

Birmingham, November 19, 1857.

XI. *On the Constitution of the Essential Oil of Rue.*

By C. Greville Williams, *Lecturer on Chemistry in the Normal College, Swansea.*

Received February 15,—Read March 18, 1858.

The essential oil procured by distillation of the rue plant with water, has already been examined by several chemists. It was analysed many years ago by Will*, who deduced from his analyses the expression $C^{20} H^{20} O^{3}$. But at that time far too little was known about the oxygenated essential oils to permit of their accurate investigation. A more minute series of experiments, made by Gerhardt in 1848†, led him to conclude that oil of rue consisted principally of the capric aldehyde, contaminated by a small quantity of some hydrocarbon. This view was considered to be confirmed by the production of capric acid when the oil underwent oxidation by means of nitric acid. But the production of an acid containing C^{20} merely rendered it probable that the rue oil did not contain *less* than 20 equivalents of carbon; it was no proof that it did not contain *more*. In fact, the action of nitric acid varies with its concentration.

Guided by ideas which need not now be detailed, I made in 1853 some experiments, with the intention of obtaining from oil of rue certain bodies of the capric series, but they only served to convince me that the views then entertained regarding the constitution of the oil were erroneous. Some curious reactions were observed, but the experiments diverging into other channels have not, as yet, been renewed. Previous to recommencing them, it has been thought necessary to make a fresh examination of the oil; the results form the subject of this communication.

On examination of Gerhardt's numbers, it will be found that, while two of his analyses agree exactly with the formula $C^{20} H^{20} O^{2}$, the vapour-density (5·83) exceeds the theoretical number (5·398) to a degree much greater than can be accounted for by an error of experiment; the number obtained being almost the correct value for the homologue $C^{2} H^{2}$ above the capric aldehyde. Moreover, the fluid analysed was purified by distillation only.

In this investigation use has been made of the invaluable reagent for the isolation and purification of aldehydes (and bodies of more or less analogous constitution), placed in the hands of chemists principally by the researches of M. Bertagnini. By its aid a perfect separation has been made of the aldehydes in oil of rue, enabling their nature to be clearly determined.

On submitting the crude oil to about a dozen fractional distillations, distillates were obtained from 160° to 238°. On treating them with the bisulphites of soda or ammonia,

* Ann. der Chem. und Pharm. xxxv. 235. † Ann. de Chim. et de Phys. [3] xxiv. 103.

great differences became apparent in their behaviour. The portions boiling between 160° and 188° were scarcely affected; they floated above the solution of the bisulphite, and after contact for weeks, showed scarcely a trace of crystalline compound. The fluids boiling at intermediate points yielded more crystals as their point of ebullition became higher; and when a boiling-point of 210° was reached, the oil (treated as before) became semi-solid in about two hours; and from that temperature to 238°, the tendency to yield crystals on agitation with the bisulphites increased.

Bisulphite of ammonia was found to be a more convenient reagent than the corresponding salt of soda, the resulting salt being more crystalline, and procurable with greater ease in a state of purity. When the fractions distilling in the twelfth rectification at 232° and upwards were treated with bisulphite of ammonia, the whole solidified, in the course of twelve hours, to a crystalline mass of such firm texture, as to be with difficulty penetrated by a glass rod. The very last fractions distilling at 260° and upwards yielded less crystalline masses, retaining traces of an empyreumatic oil.

The analyses and vapour-density determinations described in this paper were all made upon fluids obtained by the following process. The crystalline substance from the lower fractions was thrown upon a filter, and well washed with a saturated solution of bisulphite of ammonia, which mechanically carried away much of the oily impurities. The product of this operation was a snow-white mass with a rich pearly lustre. It was carefully removed to a fresh piece of filtering-paper, and, a few folds intervening, laid upon a porous tile. In the course of a few hours the mass became firm enough to be removed, and being folded in several fresh pieces of filtering-paper, was again placed between tiles and subjected to considerable pressure. This was repeated until the paper ceased to receive any stain. The crystalline solid was then transferred to a stoppered vessel, and gently heated with a strong solution of potash. In a short time the compound was decomposed, the aldehyde floating on the surface in the form of an oil.

The aldehyde thus procured was colourless; it possessed a pleasing fragrance, totally different from the nauseous odour of the plant itself. Its boiling-point, as first prepared, fluctuated considerably, arising partly from oxidation and consequent formation of other bodies, and partly from the presence of a small portion of another aldehyde. The oxidation could only be prevented by performing the operation in a current of hydrogen, an exceedingly inconvenient process in fractional distillations, the apparatus having to be taken apart every few minutes. In the course of the experiments a considerable number of specimens were obtained, but they all had the same composition and vapour-density. By carefully collecting the residues of the distillations, and redistilling in minute retorts, blown from glass tubing, about sixty grains of the second aldehyde were obtained, still however contaminated by some of the fluid having the lower formula.

The first aldehyde yielded on analysis the following numbers:—

I. ·1982 gramme gave ·5643 gramme carbonic acid and ·2329 water.

II. ·2057 gramme gave ·5843 gramme carbonic acid and ·2475 water.

III. ·2047 gramme gave ·5820 gramme carbonic acid and ·2349 water.
IV. ·2212 gramme gave ·6320 gramme carbonic acid and ·2562 water.
V. ·1986 gramme gave ·5662 gramme carbonic acid and ·2352 water.
VI. ·2138 gramme gave ·6103 gramme carbonic acid and ·2501 water.
VII. ·2131 gramme gave ·6077 gramme carbonic acid and ·2494 water.
VIII. ·2128 gramme gave ·6067 gramme carbonic acid and ·2552 water.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Carbon	77·65	77·47	77·54	77·92	77·75	77·85	77·77	77·76
Hydrogen	13·05	13·37	12·75	12·87	13·16	13·00	13·00	13·32
Oxygen	9·30	9·16	9·71	9·21	9·09	9·15	9·23	8·92
	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00

	Mean.		Calculation.	
Carbon	77·71	C^{22}	132	77·65
Hydrogen	13·07	H^{22}	22	12·94
Oxygen	9·22	O^{2}	16	9·41
	100·00		170	100·00

The above combustions were made in the manner described in the first part of my paper "On some of the Products of the Destructive Distillation of Boghead Coal*."

The annexed values were obtained in two determinations of the density of the vapour. In order to prevent oxidation, the balloon was in each case filled with hydrogen previous to immersion in the bath.

	I.	II.
Temperature of the air	18°	16°
Temperature of the vapour	247°	259°
Pressure	760	759·2 mm.
Excess of weight of balloon	·2220	·5770 gramme.
Capacity of balloon	82·5	228·0 cub. cent.
Residual hydrogen	1·0	10·0 cub. cent.
Density of vapour	5·83	5·91

The formula $C^{22} H^{22} O^{2} = 4$ volumes, requires—

22 volumes carbon vapour	0·8290 . 22 =	18·2380
44 volumes hydrogen	0·0692 . 44 =	3·0448
2 volumes oxygen	1·1056 . 2 =	2·2112
		$\frac{23·4940}{4} = 5·8735$

Experiment (mean).	Theory.
5·87	5·874

* Philosophical Transactions, 1857.

The first of these experiments yielded the same number as that found by GERHARDT. It is somewhat remarkable that the vapour-density did not induce him to adopt a formula with 22 instead of 20 equivalents of carbon.

The specific gravity of the fluid was 0·8497 at 15°. During a cold night the aldehyde was converted into a solid crystalline mass, resembling camphor. Agitation will cause it to solidify when the temperature is as high as 7°.

GERHARDT made four analyses and one vapour-density determination of oil of rue, and it is worthy of notice that two of his analyses and the vapour-density agree better with the view now proposed of its constitution than with his own. His analyses were as follows:—

	a.	*b.*	*c.*	*d.*
Carbon	77·65	77·69	76·95	77·10
Hydrogen	12·80	12·87	12·85	12·95
Oxygen	9·55	10·44	10·20	9·95
	100·00	100·00	100·00	100·00

The analysis *a* was made on the first portion of the distillate, *b* and *c* on the last third, and *d* by treating an alcoholic solution of oil of rue with gaseous hydrochloric acid, and reobtaining the aldehyde by the addition of water. It would appear that this last operation (supposed by him to yield an isomeric modification of the capric aldehyde) was in fact to some extent a process of purification, the liquid so prepared having a fruity odour, different from the oil merely purified by distillation, and therefore resembling the pure and fragrant aldehyde obtained by me.

Although the experiments detailed scarcely permit a doubt of the true nature of the substance (especially when the mode of purification is considered), still it was wished to place the matter beyond dispute. With this intention, the aldehyde obtained from the crystalline bisulphite was again treated with bisulphite of ammonia, and the whole process of purification repeated. The annexed analysis was made upon the aldehyde so obtained.

·2112 gramme gave ·6015 carbonic acid and ·2458 water.

	Experiment.	Calculation.
Carbon	77·67	77·65
Hydrogen	12·93	12·94
Oxygen	9·40	9·41
	100·00	100·00

The existence of margaritic acid having been disproved, and it having been rendered certain that cocinic acid does not contain 22 equivalents of carbon, it follows that this is the first substance yet isolated belonging to the eleventh series of bodies homologous with the derivatives of the fatty acids. It is the hydruret of the negative radical euodyle* homologous with acetyle. When carefully purified by distillation, it distils at 213° C.

* From εὐώδης.

The quantity in my possession was too small to permit of an examination of its derivatives. I had hoped to obtain euodic acid by the action of weak nitric acid upon the aldehyde, but the oxidation proceeds too far, the carbon being attacked with formation of capric acid. A barium salt gave on analysis 29·985 per cent. of barium; caprate of barium requires 28·642. During the action of the nitric acid, especially if it be not very weak, pelargonic acid is formed. A small quantity was also obtained of another substance, which was separated in the following manner. The acid solution, and the oily layer produced by cohobating euodic aldehyde and ordinary nitric acid diluted with its own bulk of water, were separated by means of a tap funnel. The oily liquid, on treatment with a strong solution of potash, partly dissolved, but, on filtration, a soft yellow substance remained on the paper. It dissolved in boiling alcohol, and separated on cooling in brilliant yellow spangles, exactly resembling chrysène as it appears when crystallized from Boghead naphtha. On examination it appeared to be the potassium salt of the highly singular substance described by CHIOZZA *, and which he regards as a compound of pelargonic acid with binoxide of nitrogen. He states that great difficulties were found in its analysis, owing to the strong tendency of the nitrogen, in the state in which it exists in the acid, to form nitrous or nitric acid, which, entering the potash apparatus, increases its weight, and in consequence causes the carbon to come out too high. The entire quantity at my disposal being only 0·2170 grm., a correct result on combustion was scarcely hoped for, especially as 0·02 had been used in a few almost microscopic preliminary experiments. The following result is, nevertheless, sufficient to identify the substance with that described by CHIOZZA.

·1976 gramme gave ·3135 carbonic acid and ·1282 water.

		Calc. $C^{18}H^{17}KN^2O^8$.
Carbon . . .	43·3	42·20
Hydrogen . .	7·2	6·64

By carefully treating the residues of the distillates, previously alluded to, a small quantity of the lauric aldehyde was obtained. It was not quite free from euodic aldehyde. Its boiling-point is about 232° C. The following is the result of its analysis:—

·1986 gramme gave ·5686 carbonic acid and ·2310 water.

	Experiment.		Calculation.	
Carbon . . .	78·1	C^{24}	144	78·26
Hydrogen . . .	12·9	H^{24}	24	13·04
Oxygen . . .	9·0	O^2	16	8·70
	100·0		184	100·00

The density of its vapour was found to be 6·182, a number considerably below that required by theory (6·366), but quite high enough, taken in conjunction with the analysis, to show the presence of lauric aldehyde in oil of rue.

* Compt. Rend. XXXV. 797 (1852).

The fluids accompanying the aldehydes in oil of rue were found not to be of much interest. That portion boiling at 154° was the most volatile. It evidently belongs to the already too numerous groups of bodies isomeric with oil of turpentine. It was not obtained quite free from an oxygenated oil. By repeated rectifications a portion was obtained yielding,—

	I.	II.
Carbon	84·63	84·88
Hydrogen . . .	11·91	11·90
Oxygen	3·46	3·22
	100·00	100·00

By cohobation over a fluid alloy of potassium and sodium, a portion of oxygen was removed without decomposition of the oil. Thus purified, a combustion gave—

Carbon	86·20
Hydrogen . . .	12·16
Oxygen	1·64
	100·00

But it was impossible to remove the whole of the oxygen in this manner; and although the object could have been attained by other methods, the trouble would have been out of proportion to the result.

Oil of rue contains, in addition to the aldehydes and terebinthinate oils, fluid hydrates of oil of turpentine. There even appeared to be fluids present homologous with borneol, but (although higher in the series) having a lower boiling-point than borneol itself, and probably, therefore, isomeric with the borneol series. The substance was obtained from the fluid refusing to combine with the alkaline bisulphites. One fluid boiling at 191° contained,—

		$C^{22} H^{26} O^2$ requires
Carbon	78·7	78·6
Hydrogen . . .	11·7	11·9
Oxygen	9·6	9·5
	100·0	100·0

Little attention was paid to these bodies, partly because they appeared to differ in different samples of oil, but chiefly because no positive guarantee of their purity could be obtained. The fact, however, was observed, that the above fluid, like borneol, yielded camphor when boiled with nitric acid.

XII. *On the Action of Ammonia on Glyoxal.*

By Dr. H. Debus. *Communicated by Professor* Tyndall, *F.R.S.*

Received May 21,—Read June 10, 1858.

If alcohol be slowly oxidized at ordinary temperatures by nitric acid, besides other substances, glyoxal, $C_2H_2O_2$, and glyoxylic acid, $C_2H_4O_4$*, are produced.

I have continued the investigation of these substances, and beg to lay before the Royal Society some of the more interesting results.

Glyoxal, of the consistency of syrup, is heated to 60° C., and mixed with about three times its bulk of warm strong ammonia. A slight effervescence takes place, and the liquid assumes a brown colour. After a few minutes small crystals of an organic base, which I shall call glycosine, commence to separate. The mixture is kept at a temperature of 60° or 80° C., as long as the quantity of crystals seems to increase. The latter are collected on a filter after the liquid has become perfectly cold, and washed with cold water. The substances contained in the brown mother-liquor will be mentioned in another part of this paper.

In order to purify the glycosine, it is dissolved in diluted hydrochloric acid, the liquid shaken with pure animal charcoal, filtered and precipitated by ammonia. The base separates as a white crystalline powder. This operation must be repeated if the substance should not be quite colourless. The mother-liquor, from which the pure glycosine separates, contains only chloride of ammonium.

Glycosine, $C_6H_6N_4$, obtained in the manner described, forms small white prisms, which, when viewed with the microscope, appear iridescent. It becomes electric on being rubbed in a mortar, and evaporates without melting when heated on platinum foil. Glycosine, heated between two watch-glasses on a sand-bath, sublimes without leaving a residue, and produces magnificent prisms, sometimes of half an inch in length. The base is inodorous, tasteless, and of the softness of talc. In cold water it is nearly insoluble, and the small quantity which is taken up by hot water, separates almost entirely in white needles when the liquid becomes cold. Hydrochloric and acetic acids dissolve glycosine very easily; and if the hydrochloric acid solution be concentrated on the water-bath and allowed to stand, the hydrochlorate presents itself in crystals sometimes of an inch in length, the appearance of which resembles sulphocyanide of potassium. The hydrochloric acid compound of glycosine comports itself with reagents in the following manner:—

1. Caustic potash, ammonia, and lime-water produce a precipitate of glycosine.

* C=12, H=1, O=16.—Phil. Mag. November 1856, and January 1857.

2. Oxalate of ammonia causes the formation of small crystals of the oxalate.

3. Iodide of potassium and sesquichloride of iron produce no change.

4. Chloride of copper gives a precipitate of fine green crystals, radiating from one centre.

5. Nitrate of silver gives a white precipitate, insoluble in nitric acid.

6. Chloride of mercury throws down a white crystalline powder, soluble in dilute hydrochloric acid.

The following experiments were made to determine the composition of glycosine:—

0·211 grm., dried over sulphuric acid, treated according to WILL and VARRENTRAPP's method, gave 1·407 grm. chloroplatinate of ammonium. The latter left, after ignition, the quantity of platinum required by the formula $NH_3, HCl + PtCl_2$. Special experiments were made to prove the purity of the materials employed. The carbon and hydrogen determination was lost, and want of material prevented me from repeating the combustion. 100 parts of glycosine contain, therefore,

Nitrogen	41·90.

Under the supposition that the formation of the substance took place according to

$$x(C_2H_2O_2)+y(NH_3)\pm z(H_2O),$$

I can only calculate the formula $C_6H_6N_4$, which requires

Nitrogen	41·79

Chloroplatinate of glycosine$=C_6H_6N_4, 2HCl+2PtCl_2$.

Bichloride of platinum was added by degrees to a concentrated solution of hydrochlorate of glycosine. At first a light brown, and afterwards a fine yellow precipitate was produced. The reason of this is, that the hydrochlorate of the base unites in more than one proportion with bichloride of platinum. In order, therefore, to obtain a pure compound, the liquid was filtered as soon as the precipitate assumed a bright yellow colour, and bichloride of platinum in *excess* added to the filtrate. Thus a homogeneous powder of yellow crystals was obtained.

This salt, dried over sulphuric acid, was employed in the following experiments:—

0·458 grm. left after ignition 0·166 grm. platinum.

0·356 grm., burnt with chromate of lead, gave 0·179 grm. carbonic acid and 0·051 grm. water.

0·625 grm., burnt with lime, gave 0·968 grm. of chloride of silver.

0·997 grm., burnt with soda-lime, gave 1·648 grm. chloroplatinate of ammonium.

In 100 parts—

Carbon	13·71
Hydrogen	1·59
Nitrogen	10·38
Chlorine	38·29
Platinum	36·24
	100·21

The formula $C_6H_6N_4$, $2(HCl, PtCl_2)$ requires—

Carbon	6	72	13·16
Hydrogen	8	8	1·46
Nitrogen	4	56	10·23
Chlorine	6	213	38·93
Platinum	2	197·4	36·10
		546·4	99·88

Boiling water dissolves this compound, but it is almost insoluble in cold water. Long-continued washing with the latter seems to abstract bichloride of platinum, and convert it perhaps into

$$C_6H_6N_4,\ HCl\ PtCl_2.$$

Glycosine is formed from ammonia and glyoxal according to the equation

$$3(\underbrace{C_2H_2O_2}_{\text{Glyoxal.}})+4(NH_3)=\underbrace{C_6H_6N_4}_{\text{Glycosine.}}+6(H_2O).$$

I showed, on another occasion, that glyoxal has the properties of an aldehyde. Its behaviour to ammonia confirms my former conclusions. The formation of amarine from oil of bitter almonds, of acetonine from acetone and ammonia, takes place in a similar manner:—

$$3(\underbrace{C_7H_6O}_{\text{Oil of bitter almonds.}})+2(NH_3)=\underbrace{C_{21}H_{18}N_2}_{\text{Amarine.}}+3H_2O$$

$$3(\underbrace{C_3H_6O}_{\text{Acetone.}})+2(NH_3)=\underbrace{C_9H_{18}N_2}_{\text{Acetonine.}}+3H_2O.$$

In all other known cases when, from an aldehyde, or the chloride of an alcohol radical and ammonia, a basic substance is formed, one or two equivalents of ammonia participate in the reaction. If ammonia and glyoxal decompose each other, four equivalents of the first transfer their nitrogen to one equivalent of the base produced. The direct derivation from ammonia of a base which contains four equivalents of nitrogen seems to me to be very interesting.

The rational formula of glycosine is probably

$$N_4\left\{\begin{matrix}C_2H_2\\C_2H_2\\C_2H_2,\end{matrix}\right.$$

C_2H_2 being equivalent to H_4.

It is worthy of notice, that in chemical decompositions very often three equivalents of an aldehyde unite and act like one molecule. I will only mention as examples,—mesitylene, acetonia, thialdine, hydrosalicylamide, and amarine.

Binoxalate of Glyoxaline, $C_2H_4N_2$, $C_2H_2O_4$.

The brown mother-liquor from which the glycosine was at first separated, is evapo-

rated on the water-bath till all the ammonia has been driven off. The remaining liquid is then mixed with about twice its bulk of a warm and concentrated solution of oxalic acid, and the mixture allowed to stand for a few hours; crystals of oxalate of glyoxaline are formed. They are redissolved in water, the solution is decolorized with charcoal, concentrated by evaporation, and left in a cold place to crystallize. After this treatment has been repeated once or twice, crystals of pure binoxalate of glyoxaline, $C_2 H_4 N_2, C_2 H_2 O_4$, are obtained. It forms small colourless prisms much more soluble in hot than in cold water. A warm concentrated solution crystallizes during filtration.

Analysis gave the following results:—

0·321 grm., dried over sulphuric acid and burnt with chromate of lead, gave 0·454 grm. carbonic acid and 0·117 grm. water.

0·466 grm., treated according to WILL and VARRENTRAPP'S method, gave 1·322 grm. chloroplatinate of ammonium. The latter left after ignition 0·58 grm. Pt.

In 100 parts,—

Carbon	38·57
Hydrogen . . .	4·05
Nitrogen	17·82
Oxygen	39·56
	100·00

The formula $C_2 H_6 N_2 O_4$ requires,—

Carbon . . .	5	60	37·97
Hydrogen . .	6	6	3·79
Nitrogen . .	2	28	17·72
Oxygen . . .	4	64	40·52
		158	100·00

This compound does not contain any water of crystallization. In order to determine the oxalic acid contained therein, 0·282 grm. were dissolved in water and precipitated with chloride of calcium and a few drops of ammonia. The weight of the precipitate, after conversion into carbonate of lime, was 0·180 grm. Since 100 parts of carbonate of lime correspond to 90 parts of oxalic acid, $C_2 H_2 O_4$, 0·180 grm. of $Ca_2 O, CO_2$ require 0·162 grm. $C_2 H_2 O_4$. Consequently 158 parts of binoxalate of glyoxaline contain 90·7, or one equivalent of oxalic acid, and for one equivalent of glyoxaline is left $C_2 H_4 N_2$.

Glyoxaline, $C_2 H_4 N_2$.

Chalk is added to a solution of binoxalate of glyoxaline, and the mixture warmed till there is no more carbonic acid escaping. The filtrate from the oxalate of lime is evaporated to the consistency of syrup, and left to stand in the exsiccator for some days. The glyoxaline crystallizes only with difficulty in prisms radiating from one centre. It melts easily, evaporates at higher temperatures in dense white fumes, and smells like

fish. The base dissolves very easily in water, turns turmeric paper brown, reddens litmus blue, and has a strong alkaline taste. It neutralizes the strong acids perfectly, and produce sprecipitates with sesquichloride of iron, nitrate of silver, chloride of copper, but not with chloride of calcium.

Chloroplatinate.—To a strong solution of hydrochlorate of glyoxaline is added bichloride of platinum. Immediately an orange-coloured crystalline precipitate falls down. A little water is added, and the mixture heated till the platinum salt has dissolved. The clear liquid is now left to cool, when the chloroplatinate of glyoxaline crystallizes in magnificent orange-coloured prisms.

0·287 grm., dried over sulphuric acid, left, after heating, 0·104 grm. platinum.

0·627 grm., burnt with chromate of lead, gave 0·309 grm. carbonic acid and 0·111 grm. water. Consequently 100 parts,—

Carbon	13·44
Hydrogen	1·96
Platinum	36·23

The formula $C_6 H_4 N_2$, $HCl\,Pt\,Cl_2$ requires—

Carbon . . .	3	36	13·12
Hydrogen . .	5	5	1·82
Nitrogen . .	2	28	10·21
Chlorine . .	3	106·5	38·84
Platinum . .	1	98·7	36·01
		274·2	100·00

FRANKLIN INSTITUTE LIBRARY.

The crude mother-liquor of the binoxalate of glyoxaline, on evaporation, gave off fumes like formic acid. Except oxalic, traces of glycolic and formic acids, no other substance could be detected in the evaporated liquid. Two modes of decomposition take place when glyoxal and ammonia act on each other:—

$$\text{I.}\quad \underbrace{3C_2H_2O_2}_{\text{Glyoxal.}}+4NH_3=N_4\left\{\begin{matrix}C_2H_2\\C_2H_2\\C_2H_2\end{matrix}\right.+6H_2O.$$

$$\text{II.}\quad \underbrace{2C_2H_2O_2}_{\text{Glyoxal.}}+2NH_3=\underbrace{C_6H_4N_2}_{\text{Glyoxaline.}}+\underbrace{CH_2O_2}_{\text{Formic acid.}}+2H_2O.$$

The second mode of decomposition is the principal one, for much more glyoxaline than glycosine is produced.

XIII. *On some Physical Properties of Ice.* By JOHN TYNDALL, *F.R.S., Professor of Natural Philosophy in the Royal Institution of Great Britain.*

Received December 17,—Read December 17, 1857.

THE observations upon Glaciers, to be recorded in a subsequent paper, led me to make some experiments upon the physical properties of ice, the results of which are, I hope, of sufficient interest to justify me in presenting them to the Royal Society.

§ I.

1. I availed myself of the fine sunny weather with which we were favoured last September and October, to examine the effects of solar heat upon ice. The experiments were made with the Wenham Lake and Norway ice. Slabs were formed of the substance, varying from one to several inches in thickness, and these were placed in the path of a beam rendered convergent by a double convex lens 4 inches in diameter, and possessing a focal distance of 10½ inches. The slabs were usually so placed, that the focus of parallel rays fell within the ice. Having first found the position of the focus in air, the lens was screened; the ice was then placed in position, the screen was removed, and the effect was watched through an ordinary pocket lens.

2. A plate of ice an inch thick, with parallel sides, was first examined: on removing the screen the transparent mass was crossed by the sunbeams, and the path of the rays through it was instantly studded by a great number of little luminous spots, produced at the moment and resembling shining air-bubbles. When the beam was sent through the edge of the plate, so that it traversed a considerable thickness of the ice, the path of the beam could be traced by those brilliant spots, as it is by the floating motes in a dark room.

3. In lake ice the planes of freezing are easily recognized by the stratified appearance which the distribution of the air-bubbles gives to the mass. A cube was cut from a perfectly transparent portion of the ice, and the solar beam was sent through the cube in three rectangular directions successively. One was perpendicular to the plane of freezing, and the other two parallel to it. The bright bubbles were formed in the ice in all three cases.

4. When the surfaces perpendicular to the planes of freezing were examined by a lens, after exposure to the light, they were found to be cut up by innumerable small parallel fissures, with here and there minute spurs shooting from them, which gave the fissures, in some cases, a feathery appearance. When the portions of the ice traversed by the beam were examined parallel to the surface of freezing, a very beautiful appearance

revealed itself. Allowing the light from a window to fall upon the ice at a suitable incidence, the interior of the mass was found filled with little flower-shaped figures. Each flower had six petals, and at its centre was a bright spot, which shone with more than metallic brilliancy. *The petals were manifestly composed of water*, and were consequently dim, their visibility depending on the small difference of refrangibility between ice at 32° Fahr. and water at the same temperature.

5. For a long time I found the relation between the planes of these flowers and the planes of freezing perfectly constant. They were always parallel to each other. The development of the flowers was independent of the direction in which the beam traversed the ice. Hence, when an irregular mass of transparent ice was presented to me, by sending a sunbeam through it, I could tell in an instant the direction in which it had been frozen.

Allowing the beam to enter the edge of a plate of ice, and causing the latter to move at right angles to the beam, so that the radiant heat traversed different portions of the ice in succession, when the track of the beam was observed through an eye-glass, the ice, which a moment before was optically continuous, was instantly starred by those lustrous little bubbles, and around each of them the formation and growth of its associated flower could be distinctly observed.

6. The maximum effect was confined to a space of about an inch from the place at which the beam first struck the ice. In this space the absorption, which resolved the ice into liquid flowers, for the most part took place, but I have traced the effect to a depth of several inches in large blocks of ice.

7. At a distance, however, from the point of incidence, the spaces between the flowers became greater; and it was no uncommon thing to see flowers developed in planes a quarter of an inch apart, while no change whatever was observed in the ice between these planes.

8. The pieces of ice experimented on appeared to be quite homogeneous, and their transparency was very perfect. Why then did the substance yield at particular points? Were they really weak points of crystalline structure, or did the yielding depend upon the manner in which the calorific wave impinged upon the molecules of the body at these points? However these and other questions may be answered, the experiments have an important bearing upon the question of absorption. In ice the absorption of the rays which produce the flowers is fitful, and not continuous; and there is no reason to suppose that in other solids the case is not the same, though their constitution may not be such as to reveal it*.

I have applied the term "bubbles" to the little bright disks in the middle of the flowers, simply because they resembled the little air-globules entrapped in the ice; but whether they contained air or not could only be decided by experiment.

* Notwithstanding the incomparable diathermaneity of the substance, M. Knoblauch finds that when plates of rock-salt are thick enough, they always exhibit an elective absorption. Effects like those above described may possibly be the cause of this.

9. Pieces of ice were therefore prepared, through which the sunbeams were sent so as to develope the flowers in considerable quantity and magnitude. These pieces were then dipped into warm water contained in a glass vessel, and the effect, when the melting reached the bright spots, was carefully observed through a lens. *The moment a liquid connexion was established between them and the atmosphere, the apparent bubbles suddenly collapsed, and no trace of air rose to the surface of the warm water.*

10. This is the result which ought to be expected. The volume of water at 32° being less than that of ice at the same temperature, the formation of each flower ought to be attended with the formation of a vacuum, which disappears in the manner described when the ice surrounding it is melted.

Similar experiments were made with ice in which true air-bubbles were enclosed. When the melting liberated the air, the bubbles rose slowly through the liquid and floated for a time upon its surface.

11. Exposure for a second, or even less, to the action of the sun was sufficient to develope the flowers (4) in the ice. The first appearance of the central star of light was often accompanied by an audible clink, as if the substance had been suddenly ruptured. The edges of the petals were at the commencement definitely curved thus: ; but when the action was permitted to continue, and sometimes even without this, when the sun was strong, the edges of the petals became serrated thus: the beauty of the figure being thereby augmented.

Sometimes a number of elementary flowers grouped together to form a thickly-leaved cluster resembling a rose. Here and there also amid the flowers a liquid *hexagon* might be observed, but such were of rare occurrence.

12. The act of crystalline dissection, if I may use the term, thus performed by the solar beams, is manifestly determined by the manner in which the crystalline forces have arranged the molecules. By the abstraction of heat the molecules are enabled to build themselves together, by the introduction of heat this architecture is taken down. The perfect symmetry of the flowers, from which there is no deviation, argues a similar symmetry in the molecular architecture; and hence, as optical phenomena depend upon the molecular arrangement, we might pronounce with perfect certainty from the foregoing experiments, that ice is, what Sir David Brewster long ago proved it to be, optically speaking, uniaxal, the axis being perpendicular to the surface of freezing.

§ II.

13. On the 25th of September, while examining a perfectly transparent piece of Norway ice, which had not been traversed by the condensed sunbeams, I found the interior of the mass crowded with parallel liquid disks, varying in diameter from the tenth to the hundredth of an inch. These disks were so thin, that when looked at in section they were reduced to the finest lines. They had the exact appearance of the

circular spots of oily scum which float on the surface of mutton broth, and in the pieces of ice first examined they always lay in the planes of freezing.

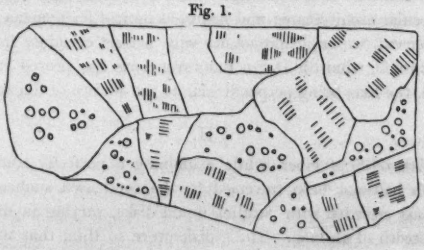
14. As time progressed this internal disintegration of the ice appeared to become more pronounced, so that some pieces of Norway ice examined in the middle of November, appeared to be reduced to a congeries of water-cells entangled in a skeleton of ice. The effect of this was rendered manifest to the hand on sawing a block of this ice, by the facility with which the saw went through it.

15. There seems to be no such thing as absolute homogeneity in nature. Change commences at distinct centres instead of being uniformly and continuously distributed, and in the most apparently homogeneous substance we should discover defects, if our means of observation were fine enough. The above observations show that some portions of a mass of ice melt more readily than others. The melting temperature of the substance is set down at 32° FAHR., but the absence of perfect homogeneity, whether from difference of crystalline texture or some other cause*, makes the melting temperature oscillate to a slight extent on both sides of the ordinary standard. Let this limit expressed in parts of a degree be t. Some parts of a block of ice will melt at a temperature of $32-t$, while others require a temperature of $32+t$: the consequence will be that such a block raised to the temperature of 32° will have some of its parts liquid, and others solid.

16. When a mass exhibiting the water-disks was examined by a concentrated sun-beam, the six leaved flowers before referred to *were always formed in the planes of the disks.*

17. In all my earlier experiments I found the rule to hold good, that both disks and flowers were developed in the planes of freezing, but I was subsequently surprised to find, in the self-same mass of ice, the disks lying in different planes. On examining such pieces I found them traversed by hazy surfaces of discontinuity, which divided the apparently continuous mass into irregular prismatic segments. When examined by allowing the red light of a fire to cross it, such ice had a beautiful appearance. The interior walls of the segments were thickly covered with rich liquid disks; in some cases the vision plunged unimpeded into the ice to a depth of several inches, while in others the prismatic segments were dotted with disks to their very centres. Fig. 1

Fig. 1.



* See Mr. FARADAY's Note on this subject at the end.

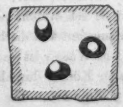
represents one of a number of cases of this kind which I had an opportunity of examining. The network of lines are the intersections of the bounding surfaces of the segments with the surface of the slab of ice: the short lines in each segment represent the sections of the disks; and it will be observed that while in each single segment their directions are alike, in no two segments is this the case. The flat rings denote that the disks, at these places, were parallel to the surface of the ice slab, while in all the other cases they were perpendicular to it.

18. I placed this slab on a table which could be caused to rotate, and bringing it into the path of a concentrated sunbeam, caused the beam to travel all round it. The little flowers started into existence with extreme suddenness and beauty. *In all cases the planes of the flowers were parallel to the planes of the disks.*

19. Hence the conclusion that the flowers are always parallel to the surface of freezing, must not go without qualification. There is no doubt that each of the fragments above referred to, possesses an optic axis perpendicular to the planes of the flowers developed in it; the directions of these axes being therefore as various as the planes aforesaid. How is this result brought about? Has the molecular structure of the ice been always what the last experiments show it to be? Sir DAVID BREWSTER's observations are in opposition to this idea. Or can it be that the ice has changed, by a rearrangement of the constituent particles of each segment, this arrangement producing the surfaces of discontinuity by which the segments are bounded? At present we are confined to mere conjectures, but I hope the coming winter will enable me to investigate this highly interesting question.

§ III.

20. What has been already said will prepare us for the consideration of an associated class of phenomena of great physical interest. The larger masses of ice which I examined exhibited layers in which bubbles of air were collected in unusual quantity, marking, no doubt, the limits of successive acts of freezing. These bubbles were usually elongated. Between two such beds of bubbles a clear stratum of ice intervened; and a clear surface layer, which, from its appearance, seemed to have suffered more from external influences than the rest of the ice, was associated with each block. In this superficial portion I observed detached air-bubbles irregularly distributed, and associated with each vesicle of air, a bleb of water which had the appearance of a drop of clear oil within the solid. The adjacent figure will give a notion of these composite cavities: the unshaded circle represents the air-bubble, and the shaded space adjacent, the water.



21. When the quantity of water was sufficiently large, which was usually the case, on turning the ice round, the bubble shifted its position, rising always at the top of the bleb of water. Sometimes, however, the cell was very flat, and the air was then quite surrounded by the liquid. These composite cells often occurred in pellucid ice, which showed inwardly no other sign of disintegration.

This is manifestly the same phenomenon as that which struck M. AGASSIZ so forcibly

during his earlier investigations on the glacier of the Aar. The same appearances have been described by the Brothers SCHLAGINTWEIT, and finally attention has been forcibly drawn to the subject in a recent paper by Mr. HUXLEY, published in the Philosophical Magazine*.

22. The only explanation of this phenomenon hitherto given, and adopted apparently without hesitation, is that of M. AGASSIZ and the Messrs. SCHLAGINTWEIT. These observers attribute the phenomenon to the diathermancy of the ice which permits the radiant heat to pass through the substance, to heat the bubbles of air, and cause them to melt the surrounding ice†.

The apparent simplicity of this explanation contributed to ensure its general acceptance; and yet I think a little reflection will show that the hypothesis, simple as it may appear, is attended with grave difficulties.

23. For the sake of distinctness I will here refer to a most interesting fact, observed first by M. AGASSIZ, and afterwards by the Messrs. SCHLAGINTWEIT. In the 'Système Glaciaire'‡ it is described in these words: "I ought also to mention a singular property of those air-bubbles, which at first struck us forcibly, but which has since received a very satisfactory explanation. When a fragment containing air-bubbles is exposed to the action of the sun, the bubbles augment insensibly. Soon, in proportion as they enlarge, a transparent drop shows itself at some point of the bubble. This drop, in enlarging, contributes, on its part, to the enlargement of the cavity, and following its progress a little, it finishes by predominating over the bubble of air. The latter then swims in the midst of a zone of water and tends incessantly to reach the most elevated point, at least if the flatness of the cavity does not hinder it."

24. The satisfactory explanation here spoken of is that already mentioned: let us now endeavour to follow the hypothesis to its consequences. Comparing equal weights of both substances, the specific heat of water being 1, that of air is 0·25. Hence to raise a pound of water one degree in temperature, a pound of air would have to lose four degrees.

25. Let us next compare equal volumes of the substances. The specific gravity of water being 1, that of air is $\frac{1}{770}$; hence a pound of air is 770 times the volume of a pound of water; and hence for a quantity of air to raise *its own volume* of water 1 degree, it must part with 770×4, or 3080 degrees of temperature.

* October, 1857.

† Il est évident pour quiconque a suivi le progrès de la physique moderne, que ce phénomène est dû uniquement à la diathermanéité de la glace (AGASSIZ, Système, page 157).

Das Wasser ist dadurch enstanden dass die Luft Wärmestrahlen absorbirte welche das Eis als diathermaner Körper durchliess (SCHLAGINTWEIT, Untersuchungen, S. 17).

‡ Page 168. The figures to which M. AGASSIZ refers in the note to this page seem to be correctly drawn, but his descriptive reference to them, though in part correct, is in part unintelligible to me. He uses the term *bulles* for the bubbles of air, and *gouttelettes* for the drops of water, and I believe the latter term is always restricted to a *liquid*. But if we restrict the term thus throughout the passage in question, there is no escape from Mr. HUXLEY's conclusion, that M. AGASSIZ has taken the air-bubbles for drops of water, and the drops of water for air-bubbles.

26. Now the latent heat of water is 142°·6 FAHR., hence the quantity of heat required to melt a certain weight of ice is 142·6 times the quantity required to raise the same weight of water 1 degree in temperature; hence a measure of air, in order to reduce its own volume of ice to the liquid condition, must lose $3080 \times 142{\cdot}6$, or 439,208 degrees of temperature.

27. This then gives us an idea of the amount of heat which, according to the above hypothesis, is absorbed by the bubble and communicated to the ice during the time occupied in melting a quantity of the latter equal in volume to the bubble, which time is stated to be brief; that is to say, the quantity of heat supposed to be absorbed by the air would, if it had not been communicated to the ice, have been sufficient to raise the bubble itself to a temperature 160 times that of fused cast iron. Had air this power of absorption, it might be attended with inconvenient consequences to the denizens of the earth; for we should dwell at the bottom of an atmospheric ocean, the upper strata of which would effectually arrest all calorific radiation.

28. It is established by the experiments of DELAROCHE and MELLONI*, that a calorific beam, emerging from any medium which it has traversed for any distance, possesses, in an exalted degree, the power of passing through an additional length of the same substance. Absorption takes place, for the most part, in the portion of the medium first traversed by the rays. In the case of a plate of glass, for example, 17½ per cent. of the heat proceeding from a lamp is absorbed in the first fifth of a millimetre; whereas, after the rays have passed through 6 millimetres of the substance, an additional distance of 2 millimetres absorbs less than 2 per cent. of the rays thus transmitted. Supposing the rays to have passed through a plate 25 millimetres, or an inch in thickness, there is no doubt that the heat emerging from such a plate would pass through a second layer of glass, 1 millimetre thick, without suffering any measureable absorption. For an incomparably stronger reason, the quantity of solar heat absorbed by a bubble of air at the earth's surface, after the rays have traversed the whole thickness of our atmosphere, and been sifted in their passage through it, must be wholly inappreciable.

29. To the sifting power of the atmosphere we must add, in the case of the glacier, the absorptive power of the ice. Some notion of this power, as compared with that of air, may be gathered from the following facts:—As regards the variation of the intensity of radiant heat with the distance, the law of inverse squares is capable of the strictest experimental verification in air, even when the source of heat is far below 212° FAHR. This implies that the absorption in the space of air through which the heat passes is too small to disturb the harmony of the law. Now a plate of ice, one-tenth of an inch thick, is absolutely impervious to heat emanating from a source, not only of 212°, but of 752° FAHR.; and is capable, moreover, of absorbing 99½ per cent. of the calorific rays emitted by an incandescent platinum wire†. (La Thermochrose, p. 164.)

* La Thermochrose, p. 202.

† I can hardly forbear drawing attention here to the remarkable influence which the element *hydrogen* appears to exercise upon radiant heat, and the longer waves of light. Wherever hydrogen enters into a

INS LIBRARY

Such, if I mistake not, are the properties of radiant heat which modern physics have revealed; and I think they render it evident that the hypothesis of M. AGASSIZ and the Messrs. SCHLAGINTWEIT was accepted without due regard to its consequences.

But as the sun does reach the lower strata of the atmosphere, it may be thought that we are protected from its effects by the radiation from the air neutralizing its absorption. The fact however is, that air may be heated to an intense degree without showing any measureable amount of radiation. The hot current from an Argand chimney produces, according to MELLONI, no sensible effect upon a delicate thermo-electric apparatus. Hence it is not because the air gets rid of its heat by radiation, but simply because its power of absorption is infinitely behind that supposed by the hypothesis of M. AGASSIZ and the Messrs. SCHLAGINTWEIT, that animal and vegetable existence at the earth's surface is possible.

When air-bubbles occurred in those portions of the ice where the liquid disks appeared, the associated water spread out on planes parallel to those of the disks, evidently in consequence of the freer yielding of the ice in these planes. Keeping this remark in view and comparing fig. 1 with fig. 10, plate 4 of M. AGASSIZ' Atlas, the resemblance of both phenomena will at once be perceived. The glacier ice, like the

compound, I think it may be predicted that it will destroy the longer undulations. For the present I will avoid speculation upon this subject, and confine myself to facts. If we examine the list of solid substances whose power to transmit radiant heat instantaneously have been examined by MELLONI, we find that those at the lower end of the list, that is, the most imperfectly diathermanous substances, all contain hydrogen. In no single case, where this element occurs, is the substance capable of transmitting rays from a source of 752° FAHR.; while in every case where it does not occur, the power of transmitting rays from this source is manifested in a greater or less degree. Amber, gum, citric acid, alum, sugar-candy, tartrate of potash and soda, are the substances which exercise this destructive agency upon the longer undulations; *ice* being the most non-diathermanous transparent body hitherto examined. Turning to MELLONI's list of liquids, the same fact reveals itself. There is a sudden fall in the power of transmission at the place where hydrogen enters the list. Protochloride of phosphorus transmits 62 per cent. of the rays incident upon it, but the next substance, hydrocarburet of chlorine, transmits only 37 per cent. From this point to the end of the Table the substances named all contain hydrogen, the list being closed by *distilled water*, which transmits only 11 per cent. of the calorific rays from an Argand lamp.

To the same element, I believe, is to be referred the difference between Sir W. HERSCHEL and SEEBECK as to the place of maximum heat in the solar spectrum. HERSCHEL found this place to be beyond the extreme red, but SEEBECK, with a prism of sulphuric acid, found it to be in the orange, while with a prism of water he found it in the yellow. MELLONI has shown that this is due to the destruction of the less refrangible rays by the two liquids, the sulphuric acid being regarded by him as acting in a manner analogous to water. In both the water and the sulphuric acid used by SEEBECK, I believe the hydrogen to be the agent which gives the observed character to the results. The *colour* of ice and water is also a necessary consequence of this hostility of the element hydrogen to the instantaneous passage of the longer undulations.

The mathematical theory of undulation is, perhaps, perfect, but the physics of the process, that is, the real affections of light and heat in their passage through bodies, are wholly unknown to us. Cases, therefore, like the foregoing, which single out a particular substance as exhibiting a special department towards light and heat, are, I think, of great value. Increased knowledge will probably enable us to connect these effects with the other properties of this substance, and thus establish physical relations which are now unknown to us.

Norway ice with which I experimented, is divided into segments by surfaces of discontinuity. The air- and water-cavities are represented as flattened, but, as in the lake ice, they seem flattened in all directions. M. AGASSIZ regards the flattening of the cavities as a certain proof that they have been squeezed flat by pressure; and he attributes the different directions of flattening to a power of independent motion possessed by each fragment. The perfect similarity, however, of the phenomena presented by the two kinds of ice must render us cautious in accepting an explanation which may apply to the one, but excludes the other.

§ IV.

30. But the question still remains, how are the water-chambers produced within the ice? Mr. HUXLEY throws out the suggestion, which our knowledge at the time of his observations rendered most probable, namely, that the water had never been frozen at all, but had preserved itself, like the liquid in the cavities of a Gruyère cheese, from the névé downwards.

31. One simple test will, I think, decide the question whether the liquid is or is not the product of melted ice. If it be, its volume must be less than that of the ice which produced it, and the bubble associated with the water *must be composed of rarefied air.* Hence, if on establishing a liquid connexion between this bubble and the atmosphere a diminution of volume be observed, this will indicate that the water has been produced by the melting of the ice.

32. From a block of Norway ice, containing such compound bubbles, I cut a prism, and immersing it in warm water, contained in a glass vessel, I carefully watched through the side of the vessel the effect of the melting upon the bubbles. *They invariably shrunk in volume at the moment the surrounding ice was melted*, and the diminished globule of air rose to the surface of the water. I then arranged matters so that the wall of the cavity might be melted away underneath, without permitting the bubble of air at the top to escape. At the moment the melting reached the cavity the air-bubble instantly collapsed to a sphere, possessing, in some cases, far less than the hundredth part of its original volume. The experiments were repeated with several distinct masses of ice, and always with the same result. I think, therefore, it may be regarded as certain that the liquid cells are the product of melted ice*.

33. Considering the manner in which ice imported into this country is protected from the solar rays, I think we must infer that in the specimens examined by me†, *the ice in contact with the bubble has been melted by heat which has been conducted through the substance without visible prejudice to its solidity.*

34. Paradoxical as this may appear, I think it is no more than might reasonably be expected from *à priori* considerations. The heat of a body is referred, at the present

* This of course refers to the lake ice examined as described. I venture to predict, however, that the same will be found true of the bubbles in glacier ice.

† And in those portions of glacier ice which are withdrawn from the direct action of the sun.

day, to a motion of its particles. When this motion reaches such an intensity as to liberate sufficiently the particles of a solid from their mutual attractions, the body passes into the liquid condition. Now as regards the amount of motion necessary to produce this liberty of liquidity, the particles at the surface of a mass of ice must be very differently circumstanced from those in the interior, which are influenced and controlled on every side by other particles. But if we suppose a cavity to exist within the mass, the particles bounding that cavity will be in a state resembling that of the particles at the surface; and by the removal of all opposing action on one side, the molecules may be liberated by a force which the surrounding mass has transmitted without prejudice to its solidity. Supposing, for example, that solidity is limited by molecular vibrations of a certain amplitude, those at the surface of the internal cavity may exceed this, while those between the cavity and the external surface of the ice may, by their reciprocal actions, be preserved within it, just as the terminal member of a series of elastic balls is detached by a force which has been transmitted by the other members of the series without visible separation*.

35. Where, however, experiment is within reach, we ought not to trust to speculation; and I was particularly anxious to obtain an unequivocal reply to the question whether an interior portion of a mass of ice could be melted by heat which had passed through the substance by the process of *conduction*. A piece of Norway ice, containing a great number of the liquid disks already described, and several cells of air and water, was enveloped in tinfoil and placed in a mixture of pounded ice and salt. A few minutes sufficed to freeze the disks to thin dusky circles, which appeared, in some cases, to be formed of concentric rings, and reminded me of the sections of certain agates. Looked at sideways, these disks were no thicker than a fine line. The water-cells were also frozen, and the associated air-bubbles were greatly diminished in size. I placed the mass of ice between me and a gas-light, and observed it through a lens: after some time the disks and water-cells showed signs of breaking up again. The rings of the disks disappeared; the contents seemed to aggregate so as to form larger liquid spots, and finally, some of them were reduced to clear transparent disks as before.

36. But an objection to this experiment is, that the ice may have been liquefied by the radiation from the lamp, and I have experiments to describe which will show the justice of this objection. A rectangular slab, 1 inch thick, 3 inches long and 2 wide, was therefore taken from a mass of Norway ice, in which the associated air- and water-cells were very distinct. I enveloped it in tinfoil and placed it in a freezing mixture. In about ten minutes the water-blebs were completely frozen within the mass. It was immediately placed in a dark room, where no radiant heat could possibly affect it, and examined every quarter of an hour. The dim frozen spots gradually broke up into little water parcels, and in two hours the water-blebs were perfectly restored in the centre of the slab of ice. When last examined, this plate was half an inch thick, and the drops of liquid were seen right at its centre.

* Of course I intend this to help the conception merely.

37. A second piece, similarly frozen and wrapped up in flannel, showed the same deportment. In an hour and a half the frozen water surrounding the air-bubbles was restored to its liquid condition. Hence no doubt can remain as to the possibility of effecting liquefaction in the interior of a mass of ice, by heat which has passed by *conduction* through the substance without melting it.

38. I have already referred to the formation of the liquid cavities observed by M. Agassiz, when glacier ice was exposed to the sun. The same effect may be produced by exposure to a glowing coal fire. On the 21st and 22nd of November I thus exposed plates of clear Wenham Lake ice, which contained some scattered air-bubbles. At first the bubbles were sharply rounded, and without any trace of water. Soon, however, those near the surface, on which the radiant heat fell, appeared encircled by a liquid ring, which expanded and finally became crimped at its border, as shown in the adjacent figure. The crimping became more pronounced as the action was permitted to continue*.

A second plate, crowded with bubbles, was held as near to the fire as the hand could bear. On withdrawing it, and examining it through a pocket lens, the appearance was perfectly beautiful. In many cases the bubbles appeared to be surrounded by a series of concentric rings, the outer ring surrounding all the others like a crimped frill.

39. I could not obtain these effects by placing the ice in contact with a plate of metal obscurely heated†, nor by the radiation from an obscure source. Indeed ice, as before remarked, is impervious to radiant heat from such a source‡. The rays from a common fire also are wholly absorbed near the surface upon which they strike, and hence the described internal liquefaction was confined to a thin layer close to this surface.

40. But not only does liquefaction occur in connexion with the bubbles, but the "flowers," already described as produced by the solar beams, start by hundreds into existence, when a slab of transparent ice is placed before a glowing coal fire. They, however, are also confined to a thin stratum of the substance close to the surface of incidence. In the experiments made in this way, the central stars of the flowers were often bounded by sinuous lines of great beauty.

41. The foregoing considerations show that liquefaction takes place at the surface of a mass of ice at a lower temperature than that required to liquefy the interior of the solid. At the surface the temperature 32° produces a vibration, to produce which, within the ice, would necessitate a temperature of $32°+x$; the increment x being the

* The blebs observed in glacier ice also exhibit this form: see fig. 8, plate 6, of the Atlas to the 'Système Glaciaire.' In fig. 13 we have also a close resemblance of the flower-shaped figures produced by radiant heat in lake ice.

† To develope water-cavities within ice a considerable time is necessary; more time indeed than was sufficient to melt the entire pieces of ice made use of in these *contact* experiments.

‡ Hence the soundness of the ice under the moraines; the sun's rays are converted into obscure heat by the overlying debris; this only affects a layer of infinitesimal depth, and cannot produce the disintegration of the deeper ice, as the direct sunbeams can.

additional temperature necessary to overcome the resistance to liquefaction, arising from the action of the molecules upon each other.

42. Now let us suppose two pieces of ice at 32°, with moistened surfaces, to be brought into contact with each other, *we thereby virtually transfer the touching portions of these pieces from the surface to the interior*, where $32+x$ is the melting temperature. Liquefaction will therefore be arrested at those surfaces. Before being brought together, the surfaces had the motion of liquidity, but the interior of the ice has not this motion; and as equilibrium will soon set in between the masses on each side of the liquid film and the film itself, the film will be reduced to a state of motion inconsistent with liquidity. *In other words, it becomes frozen and cements the two surfaces of ice between which it is enclosed**.

If I am right here, the importance of the physical principles involved are sufficiently manifest: if I am wrong, I hope I have so expressed myself as to render the detection of my error easy. Right or wrong, my aim has been to give as explicit utterance to my meaning as the subject will admit of.

§ V.

43. Mr. Faraday's experiments on the freezing together of pieces of ice at 32° Fahr., and all of those recounted in the paper published by Mr. Huxley and myself, find their explanation in the principles here laid down. The conversion of snow into névé, and of névé into glacier, is perhaps the grandest illustration of the same principle†. It has been, however, suggested to me that the sticking together of two pieces of ice may be an act of cohesion, similar to that which enables pieces of wetted glass, and other similar bodies, to stick together. This is not the case. There is no sliding motion possible to the ice. When contact is broken, it breaks with the snap due to the rupture of a solid. Glass and ice cannot be made to stick thus together, neither can glass and glass, nor alum and alum, nor nitre and nitre, at common temperatures. I have, moreover, placed pieces of ice together over night and found them in the morning so rigidly frozen together, that when I sought to separate them, the surface of fracture passed through one of them in preference to taking the surface of regelation. Many sagacious persons have also suggested to me that the ice transported to this country from Norway and the Wenham Lake may possibly retain a residue of its cold, sufficient to freeze a thin film enclosed between two pieces of the substance. But the facts already adverted to are a sufficient reply to this surmise. The ice experimented on cannot be regarded as a magazine of cold, *because parcels of liquid water exist within it.*

44. Nevertheless, as our present knowledge of the facility with which ice permits

* It is here implied that the contact of the moist surfaces must be so perfect, or in other words, the liquid film between them must be so thin, as to enable the molecules to act upon each other *across* it. The extreme tenuity of the film may be inferred from this. A thick plate of water within the ice would facilitate rather than retard liquefaction.

† On this point see the paper referred to at the commencement.

heat to pass through it by conduction is, as far as I know, absolutely null, I was glad to avail myself of an opportunity which presented itself of obtaining some approximate notion of this power. I owe this opportunity to the kindness of Mr. HARRISON, who had devised and perfected a machine for the manufacture of ice by the evaporation of ether. I first examined a mass of ice of the shape of the frustum of a cone. The diameter of the base was $10\frac{1}{2}$ inches, of the top $7\frac{1}{2}$ inches, and the length of the frustum was 2 feet. During the freezing of this mass a thermometer fixed on the ice showed a temperature of 8° below the zero of FAHR., or 40° of FAHR. below the freezing-point of water.

45. Fourteen hours after it had been frozen, the temperature of the mass, to a depth of 2 inches below the surface, was accurately 32° FAHR. At the heart of the frustum the temperature was $31\frac{1}{4}$°. The superficial portions of the frustum had been the coldest, and we see that in fourteen hours the ice of these portions rose forty degrees in temperature.

46. On the 24th of April, Mr. HARRISON had the kindness to place his excellent machine entirely at my disposition. The vessel which contained the water to be frozen was shaped like the inverted frustum of a cone, and was surrounded by a jacket, between which and the side of the frustum vaporized ether circulated; the whole being placed in a vessel of water. At 11 o'clock A.M., I placed a thermometer (A) in contact with the side of the vessel, and about 2 inches below the surface of the water. The machine commenced to act, an opalescence was soon observable on the sides, and after twenty minutes' action the thermometer was firmly imbedded in the ice. At 1 o'clock P.M., a second thermometer (B), placed at a distance of an inch from the side of the frustum, was also surrounded by ice. At $2^h\ 20^m$ P.M. a third thermometer (C) was placed at a distance of $1\frac{3}{4}$ inch from the side of the vessel, and at $5^h\ 30^m$ P.M. a fourth thermometer (D) was placed at a distance of 3 inches from the side. The observed temperatures of these thermometers at the times stated are given in the following Table:—

Time of observation.	A.	B.	C.	D.
h m				
11 A.M.	32°			
11 20	24			
12	$15\frac{1}{2}$			
1	11	$26\frac{1}{2}$		
2	$7\frac{1}{2}$	21		
3	6	$15\frac{3}{4}$	30°	
4	$2\frac{3}{4}$	13	24	
5	$\frac{1}{2}$	$9\frac{1}{2}$	20	
8	− 3	+ 4	$+11\frac{1}{2}$	+22°

At $8^h\ 30^m$ P.M. the machine was stopped and the supply of ether was cut off. The mercurial columns began to rise gradually, and at 10 o'clock P.M. they were found to be as follows:—

A.	B.	C.	D.
27°	27°	$27\frac{1}{2}$°	$28\frac{1}{2}$°

The machine rested throughout the night, and at 8 o'clock on the morning of the 25th *all the thermometers stood at* 32°.

47. The machine was set going at 8 A.M. on the 25th, and continued working until 2 o'clock in the afternoon, its office now being, not to freeze, but to cool the ice already frozen. The thermometers were read off every quarter of an hour, but it is not necessary to record all the observations. The following are the temperatures noted at 8 and $11^h\ 30^m$ A.M. and at 2 P.M.:—

Time. h m	A.	B.	C.	D.
8	32°	32°	32°	32°
11 30	+ 1	11½	23	30½
2	−11	− 9	−3	− 1

48. At $2^h\ 45^m$ the machine was stopped and the supply of ether cut off. The upper surface of the ice was covered with 2 inches of hair-felt: the water surrounding the frustum and its jacket was at a temperature of 32°; the thermometers were read off every half-hour, but I will limit myself at present to a few observations. The temperatures at 2 o'clock were those stated at the close of the last Table.

Time of observation. h m	A.	B.	C.	D.
3 15 P.M.	+11°	+ 9°	+ 6°	+ 2°
4 15	18	17	14	11½
5 15	24	22½	20	18
8 15	28½	28½	27½	26½
11 15	31	30½	30	29½

On the 26th the following temperatures were observed:—

h m	A.	B.	C.	D.
9 A.M.	32°	31¾°	31½°	31¼°
1 30 P.M.	32	32	31¾	31½

At $1^h\ 30^m$ a hole was bored in the centre of the frustum to a depth of 5 inches, and in this another thermometer (E) was placed; its temperature at $3^h\ 30^m$ P.M. was 30½°. At 8 o'clock in the morning of the 27th the observed temperatures were the following:—

A.	B.	C.	D.	E.
32°	32°	32°	32°	32°

At the termination of the experiment the water surrounding the frustum was at a temperature of 36° FAHR.

49. These experiments show, that however bad the conducting power of ice, in comparison with other substances, may be, the assumption that blocks of it which have been preserved in this country through months of summer weather should still possess a magazine of cold beyond that due to a temperature of 32°, is wholly imcompatible with the physical character of the substance.

§ VI.

50. In a very interesting paper communicated to the British Association during its last meeting, Mr. JAMES THOMSON has explained the freezing together of two pieces of ice at 32° in the following manner:—"The two pieces of ice, on being pressed together at their point of contact, will at that place, in virtue of the pressure, be in part liquefied and reduced in temperature, and the cold evolved in their liquefaction will cause some of the liquid film intervening between the two masses to freeze." I am far from denying the operation under proper circumstances of the *vera causa* to which Mr. THOMSON refers, but I do not think it explains the facts. For freezing takes place without the intervention of any pressure by which Mr. THOMSON's effect could sensibly come into play. It is not necessary to squeeze the pieces of ice together; one bit may be simply laid upon the other and they will still freeze. Other substances besides ice are also capable of being frozen to the ice. If a towel be folded round a piece of ice at 32°, they will freeze together. Flannel is still better. A piece of flannel wrapped round a piece of ice freezes to it sometimes so firmly that a strong tearing force is necessary to separate both. Cotton wool and hair may also be frozen to ice without the intervention of any pressure which could render Mr. THOMSON's cause sensibly active*.

51. But there is a class of effects to the explanation of which the lowering of the freezing-point of water by pressure may, I think, be properly applied. The following statement is true of fifty experiments or more made with ice from various quarters. A cylinder of ice 2 inches high and an inch in diameter, was placed between two slabs of box-wood and submitted to a gradually increasing pressure. Looked at perpendicular to the axis, cloudy lines were seen drawing themselves across the cylinder; and when the latter was looked at obliquely, these lines were found to be the [illegible]ions of dim hazy surfaces which traversed the cylinder, and gave it an appearance closely resembling that of a crystal of gypsum whose planes of cleavage had been forced out of optical contact by some external force.

Fig. 2 represents the cylinder looked at perpendicular to its axis, and fig. 3 the same cylinder where looked at obliquely.

Fig. 2.

Fig. 3.

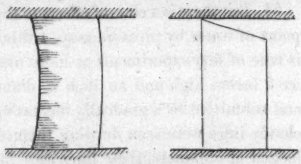
* It might perhaps be stated generally, that those substances which cause the precipitation of water from the gaseous to the liquid state, are also most influential in converting the liquid into the solid. "Hemp, wool, hair," are also the substances on which the so-called *ground-ice* is formed most readily. See ARAGO's Report, *Annuaire pour l'an* 1833.

52. To ascertain whether the rupture of optical contact which these experiments disclosed was due to the intrusion of air between two separated surfaces of ice, a cylinder of ice, 2 inches long and 1 inch wide, was placed in a copper vessel containing ice-cold water. The ice-cylinder projected half an inch above the surface of the water. Placing the copper vessel on a slab of wood, and a second slab of wood upon the cylinder of ice, the whole was subjected to pressure. When the hazy surfaces were well developed in the portion of the ice above the water, the cylinder was removed and examined. The planes of rupture extended throughout the entire length of the cylinder, just the same as if it had been squeezed in free air.

Still the removal of the cylinder from its vessel might be attended with the intrusion of air into the fissures. I therefore placed a cylinder of ice, 2 inches long and 1 inch wide, in a stout vessel of glass, which was filled with ice-cold water. Squeezing the whole, as in the last experiment, the surfaces of discontinuity were seen forming *under the liquid* quite as distinctly as in air.

53. The surfaces are due to compression, and not to any tearing asunder of the mass by tension, and they are best developed where the pressure, within the limits of fracture, is a maximum. A cylindrical piece of ice, one of whose ends was not parallel to the other, was placed between slabs of wood and subjected to pressure. Fig. 4 shows the disposition of the experiment. The effect upon the ice-cylinder was that shown in fig. 5, the surfaces being developed along that side which had suffered the pressure.

Fig. 5. Fig. 4.



54. Sometimes the surfaces commence at the centre of the cylinder. A dim small spot is first observed, which, as the pressure continues, expands until it sometimes embraces the entire transverse section of the cylinder.

55. On examining these surfaces with a pocket-lens, they appeared to me to be composed of very minute water parcels, like what is produced upon a smooth cold surface by the act of breathing. Were they either vacuous plates, or plates filled with air, their aspect would, on optical grounds, be far more vivid than it really was.

56. A concave mirror was so disposed, that the diffused light of day was thrown full upon the cylinder while under pressure. Observing the expanding surfaces through a lens, they appeared in a state of intense commotion; this was probably due to the molecular tensions of the little water parcels. This motion followed closely on the edge of the surface as it advanced through the solid ice. Once or twice I observed the hazy surfaces pioneered through the mass by dim offshoots apparently liquid. They constituted a kind of negative crystallization, having the exact form of the crystalline spines and spurs produced by the congelation of water upon a surface of glass. I have no doubt, then, that these surfaces are produced by the liquefaction of the solid in planes perpendicular to the direction of pressure.

57. The surfaces were developed with great facility where they corresponded to the surfaces of freezing. Wherever the liquid disks before described were observed, the surfaces were always easily developed in the planes of the disks. By care I succeeded, in some cases, in producing similar effects in surfaces at right angles to the planes of the disks, but this was very difficult and uncertain.

I think the following new facts have been established in the foregoing paper:—

1. The interior of a mass of ice may be melted by *radiant heat* which has passed through exterior portions of the substance without melting them.

2. In the dissolution of the ice thus effected, the substance yields by the formation of liquid spaces, each possessing the shape of a flower with six petals, a small vacuum being formed at the centre of each flower.

3. These flowers are generally formed in planes parallel to the surface of freezing, but some of the specimens of ice examined were divided into prismatic segments by surfaces of discontinuity. Each distinct segment had its own system of flowers arranged in parallel planes, but the parallelism did not extend to the flowers of two distinct segments. This subject requires further investigation.

4. The appearance presented by masses of lake ice composed of these segments, resembles that of certain specimens of glacier ice in which the air- and water-cavities are flattened in different planes. Hence the explanation of the latter, which refers them to actions peculiar to the glacier, must be received with caution.

5. The explanation hitherto given of the water associated with the air-bubbles in glacier ice is untenable. In this paper the phenomenon is explained in accordance with the dynamical theory of heat. It is sought to be shown that, owing to the mutual action of the ice-molecules, a quantity of heat which has been *conducted* through the substance without prejudice to its solidity may liberate the molecules which bound an internal cavity, and thus produce water-cells in association with the bubbles of air.

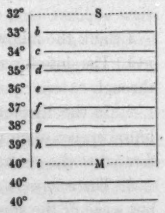
6. The converse of this takes place where two moist surfaces of ice at 32° FAHR. are brought into contact. Superficial portions are thus virtually rendered central; liquefaction is checked, the film of moisture on the surfaces in contact congeals, and the pieces of ice freeze together. To this process the term *regelation* has been applied.

7. By the application of pressure parallel surfaces of discontinuity are formed in lake and river ice perpendicular to the directions in which the pressure is exerted; thus giving the substance the appearance of selenite, in which the planes of cleavage are not in optical contact. The discontinuity consists in the liquefaction of the ice in these planes by the pressure. Such surfaces are formed with great facility parallel to the planes in which the liquid flowers are formed by radiant heat, while it is very difficult to produce them perpendicular to these planes. Thus, whether we apply heat or pressure, lake ice melts with peculiar facility in certain directions.

Note from Mr. Faraday.

My dear Tyndall,

Have the following remarks, made in reference to the irregular fusibility of ice, to which you drew my attention, any interest to you, or by an occasional bearing on such cases, any value in themselves? Deal with them as you like.



Imagine a portion of the water of a lake about to freeze, the surface S being in contact with an atmosphere considerably below 32°, the previous action of which has been to lower the temperature of the whole mass of water, so that the portion below the line M is at 40°, or the maximum density, and the part above at progressive temperatures from 40° upwards to 32°; each stratum keeping its place by its relative specific gravity to the rest, and having therefore, in that respect, no tendency to form currents either upwards or downwards. Now generally, if the surface became ice, the water below would go on freezing by the cold conducted downwards through the ice; but the successive series of temperatures from 32° to 40° would always exist in a layer of water contained between the ice and the dense water at 40° below M. If the water were *pure*, no action of the cold would tend to change the places of the particles of the water or cause currents; because the lower the cold descended, the more firmly would any given particle tend to retain its place above those beneath it: a particle at *e*, for instance, at 36° Fahr., would, when the cold had frozen what was above it, be cooled sooner and more than any of the particles beneath, and so always retain its upper place as respects them.

But now, suppose the water to contain a trace of saline matters in solution. As the water at 32° froze, either at the surface or against the bottom of the previously-formed ice, these salts would be expelled; for the ice first formed (and that *always* formed, if the proper care be taken to displace the excluded salts) is perfectly free from them, and pure. The salts so excluded would pass into the layer of water beneath, and there produce two effects: they would make that layer of greater specific gravity than before, and so give it a tendency to sink into the warmer under layer; but they would also make it require a lower temperature than 32° for congelation; this it would acquire from the cold ice above, and by that it would become lighter and float, tending to remain uppermost; for it has already been shown that the diminution of temperature below 32° in sea water and solution of salts, is accompanied by the same enlargement of bulk as between 32° and 40° with pure water. The stratum of water, therefore, below the ice, would not of necessity sink because it contained a little more salt than the stratum immediately below it; and *certainly would not* if the increase of gravity conferred by the salts was less than the decrease by lowering of temperature. An approximation of the strata between the freezing place and the layer at 40° would occur, *i. e.* the distance between these temperatures would be less, but the water particles would keep their respective places.

When water freezes, it does not appear that this process is continuous, for many of the characters of the ice seem to show that it is intermittent; *i. e.* either a film of ice is formed, and then the process stops until the heat evolved by solidification has been conducted away upwards, and the next stratum of water has been sufficiently cooled to freeze in turn; or else the freezing being, so to speak, continuous, still is not continued at the same constant rate, but, as it were, by intermittent pulsations. Now it may well be, when a layer next the previously-formed ice, and containing an undue proportion of salts, has been cooled down to its required temperature for freezing (which would be below 32°), that on freezing, the congelation will pervade at once a certain thickness of the water, excluding the salts from the larger portion of ice formed, but including them as a weak solution within its interstices. The next increment of cold conducted from the ice above would freeze up these salts in the ice containing them, at the same time that a layer of pure ice was formed beneath it. Thus a layer of ice fusible at a lower temperature than the ice either above or below it might be produced; and by a repetition of the process many such layers might be formed.

It does not follow necessarily that the layers would be perfectly exact in their disposition. Very slight circumstances tending to disturb the regularity of the water-molecules would be sufficient, probably, to disturb the layers more or less. Ice contains *no* air, and the exclusion of a minute bubble of air from the water in the act of freezing might disturb the direction and progress of the congelation, and cause accumulation of the extra saline liquid in one spot rather than another: so might the tendency to the formation of little currents, either arising from the separation of the saline water from the forming ice, or from the elevation of temperature in different degrees at those places where the congelation was going on at different rates.

The effect would not depend upon the quantity of salts contained in the freezing water, though its degree would. The proportion of salts necessary to be added to pure water to lower its freezing-point 1° FAHR. may be very sensible to chemical tests, but the proportion required to make the difference $\frac{1}{100}$th or $\frac{1}{1000}$th of a degree would be far less: and if we suppose that only $\frac{1}{20}$th of a piece of ice is brought into the condition of melting before the rest of the mass, and that the salts in that proportion were originally in the *whole* of the water, then its quantity there may be so small as to escape detection except by very careful analysis. However, it would be desirable to examine the water chemically which is produced by ice distinguished by having in its interior much, that liquefies before the rest.

It is easy to make ice perfectly free from air, and, as I believe, from salts, by a process I formerly described. It would be interesting to see if such ice had within it portions melting at a lower temperature than the general mass. I think it ought not.

Ever truly yours,

M. FARADAY.

Royal Institution,
9th December, 1857.

XIV. *Researches on the Intimate Structure of the Brain, Human and Comparative.*—First Series. *On the Structure of the* Medulla oblongata. *By* J. Lockhart Clarke, *Esq., F.R.S.*

Received June 18,—Read June 18, 1857.

(1.) Galen believed that the *medulla spinalis* commences as high up as the lower border of the *pons Varolii.* This, like nearly every other, opinion of the Greek anatomist was adopted by all his successors until the time of Sylvius and Vesalius. Sylvius traced the origin of the spinal chord from the whole base of the brain[1]; Vesalius, only from the *corpora quadrigemina*[2]. Columbus[3], Varolius[4], Spigelius[5], Laurentius[6], Riolanus[7], Highmore[8], described it as arising by two roots,—one large, from the entire base of the brain; the other small, from the cerebellum. But Piccolhomini introduced a better description of these parts, by restricting the term "medulla *spinalis*" to the contents of the spinal column; while to the whole *intra-cranial* prolongation along the base of the brain, he applied the term "medulla *oblongata*"[9], which has been retained to the present day, though many anatomists have differed with regard to the number of parts it has been supposed to comprehend. According to Willis[10], it includes the *whole base* of the brain, from the *corpora striata*—which he called "medullæ oblongatæ apices"—to the *foramen magnum.* The same view was adopted by Vieussens[11], Winslow[12], and others; while Rolando[13] employed the term in a more restricted sense; and Ridley[14], who did the same, substituted for it the term "isthmus," and Chaussier[15] that of "mesocephale," which included the *pons, tubercula quadrigemina*, with the *superior peduncles of the cerebellum*, and not the pons *only*, as sometimes stated. Flourens[16], again, on the ground of his experimental inquiries,—which led him to conclude that the seat of *excitability* begins or ends with the *corpora quadrigemina*,—limits the *medulla oblongata* between these bodies and the eighth pair of nerves. In this country the

[1] Isagoge (1556), lib. iii. cap. xxii.
[2] De Humani corporis Fabricâ, lib. iv. and vii.
[3] De Re Anatomica, p. 367 (1562).
[4] De Nervis Opticis, p. 128.
[5] De Humani Corporis Fabricâ, p. 295 (1627).
[6] Historia Anatomica, p. 529 (1600).
[7] Anthropographia, lib. v. (1618).
[8] Corp. Hum. Disquisit. Anat. lib. i. (1651).
[9] Anatomicæ Prælectiones, lib. 5. Lect. iii. and v. (1586). The whole of the description is excellent, and very superior to that of any previous anatomist.
[10] Cerebri Anatome, cap. ii. (1664).
[11] Neurographia Universalis (1684).
[12] Exposition Anatomique, Traité de la Teste, p. 126 (1695).
[13] Recherches Anatomiques sur la Moëlle allongée.
[14] Anatomy of the Brain, p. 126 (1695).
[15] De l'Encéphale, p. 106.
[16] Recherches Expérimentales sur les Propriétés et les Fonctions du Système Nerveux, pp. 21 and 239.

medulla oblongata is generally understood to extend from near the points of the *anterior pyramids* to the lower border of the *pons*, and as such it is described in this memoir.

(2.) It is well known that in the *spinal chord* the columns of white and grey substance are parallel to each other, and preserve the same relative position throughout their entire course; but in the *medulla oblongata* these parts not only assume a different arrangement, by becoming more or less blended with each other and with new structures, but frequently pursue a curvilinear direction in different planes inclined at varying angles. It is evident, therefore, that transverse and longitudinal sections, however transparent they may be made, must be insufficient, when employed alone, to complete the examination of so intricate a structure. For this reason, after having made myself thoroughly acquainted with the microscopical anatomy of these parts, and traced their relations and connexions, as far as possible, by my own method of preparation, which I find superior to any other that I have seen of the same kind, I then employed, in conjunction with it, the method of Reil; so that when necessary, the structure revealed at different stages of the dissection was compared with transparent sections through the same parts. Great assistance was also obtained by making, simply for my own use, as I dissected through the depth of a part, a multitude of sketches, which were placed side by side and carefully examined in succession: the plan is tedious and demands patience, but can be confidently recommended to anatomists as a valuable expedient for ascertaining the arrangements of a complicated and intricate structure of which the parts are so continually changing their course and relative position, in varying planes, that in the dissection each must necessarily be destroyed whilst seeking its relation to others*.

Medulla oblongata.

(3.) Anatomists are aware that the *medulla spinalis* consists externally of longitudinal white fibres, but internally of grey substance; and that the latter communicates with the surface by means of the posterior-lateral sulcus which divides the white substance of each lateral half into a posterior and an antero-lateral column. Through this sulcus or fissure, a few of the roots of the spinal nerves are connected with the central grey portion, while the rest reach it through the posterior white columns, to which, therefore, they are exclusively attached, as I first pointed out in a former communication to the Royal Society†. In the medulla oblongata, a considerable difference exists in the arrangement and relative position of the white and grey columns, and new structures are superadded. Fig. 5, Plate XII. represents the posterior aspect of the human medulla oblongata, and fig. 6 a side view of the same, enlarged. On each side of the anterior median sulcus is the *corpus pyramidale anterius* (*i i*, figs. 6 and 9). Adjoining this, along its outer border, we find the *olivary column* (*h*, fig. 6), which contains or encloses the *corpus olivare*, and is separated by the lateral column (*g*) and by the *posterior*

* In the method I formerly employed, I have succeeded in making very great improvements, which will be explained on some future occasion.

† Philosophical Transactions, 1851. Part II.

grey cornu or *column* (*f*) from the *corpus restiforme* (*a*). At the commencement of the fourth ventricle, the *corpora restiformia* (*a*, figs. 5 and 6) diverge to form its lateral boundaries; and between them and the posterior median sulcus, they enclose the posterior pyramids, or *corpora pyramidalia posteriora* (*bb*), which diverge in a similar manner at the point of the calamus scriptorius.

(4.) At the lower part of the medulla oblongata, the *gelatinous substance*, or extremity of the posterior cornu, reaches the surface, and enlarging as it ascends, forms a prominent column (fig. 6 *f*, Plate XII.), which near the olivary body becomes overlaid and concealed by a new system of transverse *arciform* fibres. This grey column, which was first described and called by ROLANDO the *tuberculo cinereo—tubercule cendrée*,—is generally believed to appear on the surface of the human medulla only; but this opinion is erroneous, for I have found it comparatively larger, or at least more prominent, in some Mammalia, as the Cat, in which its upper part, where the *arciform* fibres commence, presents a well-marked and rounded head or projection. The anterior (or as seen in fig. 6, the lower) border of the *tuberculo cinereo* rests on the lateral column which separates it from that which encloses the olivary body.

(5.) *Of the Arciform Fibres.*—The fibres so named appear in part on the lateral surfaces of the medulla, and have been somewhat differently described by SANTORINI, MALACARNE, ROLANDO, ROSENTHAL, SOLLY, and JOHN REID. In Man they vary considerably in distinctness, and sometimes apparently in arrangement; but in a great number of specimens which I carefully examined, their general course in each was found to be alike. Those on the right side of the human medulla are represented in fig. 6*. These arciform fibres may be divided into two layers—*superficial* and *deep*. The *deep* layer will be described further on, as part of the upper region of the medulla. The *superficial* layer, for convenience of description, may in turn be divided into two sets. The *first* set are entirely transverse in their course, and appear externally as an arched and flattened band extending round each side of the medulla from the anterior sulcus to the posterior columns, especially the restiform body, through which they interlace in a very intricate manner (see fig. 36, Plate XVII. *x'*); but if this band, in a properly-prepared transverse section, be examined with a sufficient magnifying-power, it may be seen to be partly formed by the convexities of many subordinate series of arcs, of many sizes, and proceeding from different depths and regions of the medulla. In three situations these are most numerous and conspicuous. One series issue from the substance of the anterior pyramid, particularly from its posterior portion, where a vesicular network or plexus and small groups of cells are developed, and whence a kind of radiation may be observed (see fig. 36, Plate XVII.): the next series issue also from the back of the pyramid, and turn round the surface of the olivary body to the lateral column, where they join the

* It may be proper to state, that in any single medulla they are seldom seen so distinctly as they are represented in this figure, which was drawn from picked and well-marked specimens that had been macerated for some hours in spirit and then treated with a mixture of spirit and acetic acid, after the membranes were removed.

deep layer in a plexus which contains a peculiar group of cells, to be described further on (see figs. 30 to 32, and fig. 36): the third series are continued backwards from the same plexus and from the front of the *tuberculo cinereo*, around the surface of which they turn to spread out and interlace with the fibres of the posterior columns (same figs.); but while crossing the *tuberculo cinereo*, which they entirely overlay, a few turn off and take a downward course along its surface, as represented in fig. 6, Plate XII. *f*. When this first set or band of arciform fibres (A′, fig. 36, Plate XVII.) are traced round the surface of the pyramid towards the bottom of the anterior sulcus, they are found to embrace closely the *side* of the pyramid, where in the upper part of the medulla is developed a layer of cells from which some take their origin (A). Passing backwards in a slightly oblique or ascending direction, they may be seen in a good transverse section, made in a corresponding plane, to have the following destinations:—some, as already stated, sweep round and *into* the back of the anterior pyramid, amongst the vesicular groups or plexus located there; some pass deeply backwards to the lateral and posterior columns of the same side; others cross obliquely to those of the opposite side, decussating through the *raphè* with fibres from the opposite band (B, fig. 36); *below* the olivary bodies, these latter fibres are not numerous; for those that proceed from the posterior and lateral columns to decussate through the now commencing *raphè*, run for the most part into the *substance* of the opposite pyramid, and but sparingly round its periphery; but in the *upper* part of the medulla, as will be shown further on, they are exceedingly abundant behind the anterior sulcus (see fig. 36). The remaining fibres of the arciform band, on reaching the bottom of the sulcus, return in a series of loops to be continuous with the band that embraces the opposite pyramid (fig. 36).

(6.) The *second* set of superficial fibres proceed from the substance of the anterior pyramid, nearer the lower border of the *pons Varolii* (fig. 6 J, Plate XII.). Curving downwards and backwards, they sweep over and around the lower end of the olivary body to re-ascend obliquely with the first set to the upper extremity of the restiform column. These fibres are sometimes very numerous, and often appear like a distinct fasciculus of the pyramid. As the *former* set were traced from the bottom of the anterior sulcus to the *central* and *posterior parts* of the medulla, it is probable that these have similar connexions with corresponding portions of the *pons*. Although, for the sake of clearness and facility of comprehension, this arciform system of fibres has been divided into separate layers, it may be well to observe, that there is no distinct line of separation between them, and that they all intermingle and communicate in an intricate manner.

(7.) In most of the Mammalia the arciform fibres are very conspicuous, but less intricate in their arrangement than those of the human medulla. As in Man, they are connected with the anterior pyramid and olivary body, as well as with the lateral column, and ascend obliquely backwards, in a broad quadrilateral band, to the posterior pyramids and restiform columns. Fig. 7, Plate XII. represents their arrangement in the Sheep. In the Cheetah or hunting Leopard (fig. 9), they appear to cover nearly the

whole of the medulla on each side, and to be developed in a remarkable degree. In birds, reptiles and fishes they may be seen without difficulty.

Of the Corpora Pyramidalia Anteriora.

(8.) *External appearance.*—The anterior pyramidal columns were first pointed out in the plates of EUSTACHIUS towards the end of the sixteenth century, and were so named by WILLIS, who considered them as the channels by which the animal spirits were conveyed from the cerebellum to the par vagum and contiguous nerves*. In Man, as is well known, they are largely developed, and appear at the lower border of the *pons* as two thick and rounded cords, which flatten as they descend to meet each other at a point. They are also of considerable but variable size in all the Mammalia, and in some of the larger beasts of prey, as the *Lion*, *Hyæna* and *Jaguar*, I have found their external dimensions to be nearly, if not quite, equal to those of Man; but in depth they are mostly smaller among this class of animals. Well marked, prominent and rounded in the *Quadrumana*,—at least in the *Simiadæ*,—they are broad and flat, but usually longer in the *Herbivora*; and in the Elephant, although far from proportionally broad in relation to the size of the brain, they are long and tapering. "Dans l'hypothèse," says SERRES, "que les pyramides sont les racines des lobes cérébraux, leur développement devrait être en raison directe de ceux-ci; or c'est ce qui n'est pas; les pyramides sont moins fortes chez l'homme que chez les singes; elles sont plus prononcées aussi chez les cétacées. Cette prédominence des pyramides se continue chez les carnassiers, le lion, l'ours, le raton, la loutre; chez les pachydèrmes et les ruminans†." *In relation to the size of the cerebrum*, it is true that the anterior pyramids are smaller in Man than in some of these animals, particularly the larger *Carnivora*, as the Lion and Hyæna; but *actually* their dimensions are in most instances much greater. In the *Herbivora* especially, the superficial breadth of the pyramids is no indication of their actual bulk, which can be ascertained only by means of transverse sections; for although they are frequently very broad, and rendered prominent at one part by the olivary bodies behind them, they are much more shallow than in Man, and their decussating fibres are much less numerous, as will be shown at a future page‡.

(9.) *Structure.*—Perhaps no question in anatomy has been the subject of greater dispute than that which concerns the *decussation* of the anterior pyramids. The opponents have been nearly equal in number and celebrity, and the confidence with which they have maintained their opinions has rendered the case somewhat remarkable§.

* Cerebri Anatome, cap. 3 (1664). † Anatomie Comparée du Cerveau, tom. ii. p. 187.

‡ I must acknowledge the readiness and kindness with which Mr. QUEKETT and Mr. MURIE, of the Royal College of Surgeons, assisted me in procuring the brains of many of these animals.

§ For instance, SANTORINI, speaking of the decussation, observes, "Nos autem sic eam luculenter conspeximus, sic evidenter, ubi apta incidere cadavera demonstravimus, ut nulla ampliùs nobis de hac re supersit dubitandi ratio" (Observationes Anatomicæ, cap. iii. 1724). On the other hand, the illustrious and laborious HALLER, after describing the anterior median sulcus, continues, "Hanc rimam si diduxeris, fibræ quasi medullares adparent, quæ a dextra columna medullæ oblongatæ in sinistram transeunt, transversæ

The decussation was first asserted by DOMENICO MISTICHELLI in 1709*. It was confirmed and more clearly pointed out the following year by the excellent POURFOUR DU PETIT†; and has since been described by SANTORINI, RACHETTI, WINSLOW, LIEUTAUD, SCARPA, GALL, DUVERNEY, SŒMMERING, VALENTIN, BURDACH, TIEDEMANN, ROSENTHAL, CRUVEILHIER, SERRES, REID, FOVILLE, SOLLY, KÖLLIKER. On the other hand, it has been denied by HALLER, MORGAGNI, BOYER, SABATIER, CHAUSSIER, PROCHASKA, VICQ D'AZYR, DUMAS, BICHAT, ROLANDO, MUNRO, DESMOULINS, and more recently by STILLING‡. At the present day the balance of opinion is decidedly in favour of a decussation, although the late microscopical researches of STILLING may have added some weight to the opposite side§. I am prepared, however, to place the fact beyond all possibility of doubt; for a cursory inspection of my preparations is sufficient to show that a complete and complicated decussation actually takes place. But still the real composition and elementary structure of the pyramids, as I shall now proceed to show, has not hitherto been accurately described.

(10.) Until the commencement of the present century, it was believed by those who admitted the fact in question, that the anterior pyramids are formed by a decussation between the *anterior* columns of the spinal chord. ROSENTHAL‖ corrected this error by pointing out the important fact that the fibres of decussation proceed from the *lateral columns*; but at the same time he thought that from the latter the whole of the pyramids are formed as new or separate structures by running along the fissure between the anterior columns, which they thrust aside in their course. Such is still the general opinion, but such is not the correct one, as I shall endeavour shortly to explain.

(11.) At the lower extremity of the human *medulla oblongata* (figs. 10 and 11, Plates XII. and XIII.), the *posterior* and *lateral white* columns are *broader* and *deeper*, but the *anterior* (I) are in every way *less* than in the dorsal or lumbar region. The central canal is entirely closed by a mass of granular matter, and is much nearer the bottom of the

quidem, quas nunquam, cum sæpe inquisivissem, vidi decussari, aut ad obliquos se secare angulos."—Elementa Physiologiæ, lib. x. tom. iv. p. 80.

* Trattato dell' Apopplesia, cap. iv. p. 13. As the work is uncommon, and I have not seen the passage that is referred to anywhere quoted, I here subjoin the principal portion. "Arrivati all' intorno, e ultimo velame si è osservato, che tutto quel caudice al di fuori si può assomigliare ad una treccia di Donna, posciache molti manipoli di fibre rette sono sovraposti à molti trasversali, molti obliqui alli trasversali, et alli retti, e seguitando questo intrecciamento ciascun ordine ritorno à sovraporsi, e sottoporsi, sinche le dette fibre escano dalla treccia trasversalmente per formare li nervi spinali, che sono ne i lati."

† Lettres d'un Médecin des Hopitaux du Roi. Namur, 4to. p. 12; accompanied with figures, which are very far superior to those of MISTICHELLI.

‡ Ueber die Medulla Oblongata.

§ "A crossing of the pyramid-fibres is nowhere to be perceived," he says, "Eine Kreuzung der Pyramidenfasern ist nirgends wahrzunehmen." He attributes such an appearance to the unsymmetrical manner in which the alternate bundles on each side meet and indigitate (Ueber die Medulla Oblongata, p. 29). He also describes these bundles of fibres as arising from the anterior commissure at the bottom of the fissure, p. 27.

‖ Ein Beitrag zur Encephalotomie. 8vo. Weimar, 1815.

anterior than of the *posterior* median sulcus; for the grey substance behind it has become more ample than in any region of the *medulla spinalis*; so that with the lateral portions it presents a kind of quadrilateral mass, which is prolonged in front and behind, on either side, to form the anterior and posterior cornua. The *anterior* cornu is thick, club-shaped, short, yet reaches nearly to the surface, for the corresponding white column is extremely shallow. The *posterior* cornu, on the contrary, is very slender and long, and projects obliquely backwards to within a line or two of the surface, where it expands into a kind of tuft, or irregularly oval mass (f), which is frequently broken into two parts, of which the most anterior is sunk, as it were, in the lateral column. This tuft or expanded portion might be termed the *caput* cornûs, and its long and narrow portion, the *cervix*. The outer part, or border of the *caput* cornûs, is the *gelatinous substance*; its interior is more opake, and pierced by a multitude of longitudinal bundles. The *cervix* cornûs is also intersected by a number of nearly flat longitudinal bundles, which in a transverse section appear as fusiform streaks in its course. Many of the fibres of the posterior nerve-roots (f'), after traversing the gelatinous substance, run out and disperse through the posterior column (see fig. 11 f'''); some cross over to the opposite side, behind the central canal; the rest, between the flat longitudinal bundles, curve forward to the anterior cornu, and in part run out at intervals through the antero-lateral column. The gelatinous substance contains numerous small and large cells, which are spherical, oval, fusiform, and triangular; and the *cervix* cornûs abounds with others of small average size and which are often extremely minute: these are oval in various degrees, or exceedingly fusiform in the direction of the fibres, with which their processes, extending to a great length, run side by side, or parallel. The whole lateral portion of the central grey substance (figs. 10 and 11) contains cells of the same kind, with a crowd of others that are spherical, oval or angular, but of great disparity in size: the smallest are less than the $\frac{1}{4000}$th of an inch in diameter, while some of the largest are nearly equal to those of the anterior cornu.

(12.) From the lateral border of the entire grey substance (figs. 10 and 11), a beautiful network of blood-vessels and fibres is prolonged through the lateral column, which is divided by its meshes into a multitude of separate fasciculi of different shapes and thickness. With the fibres, which at first are but few, a number of cells, like those of the grey substance, extend through the network, and are apparently connected with each other between the fasciculi of the white columns. Those of the anterior part (fig. 10), in Man, are by far the most abundant and the largest; they are oval, fusiform, triangular or variously branched, and may not only be traced uninterruptedly to the very centre of the anterior cornu, but many of the most distant, off the skirts of the network, are connected with it by processes of remarkable length.

(13.) It is from the fasciculi of the lateral column, enclosed in the meshes of this network, that the fibres proceed in a transverse direction, with others from the grey substance, to form the chief portion of the opposite anterior pyramid (see figs. 11 and 12). As they bend round to take this direction, they interlace and intertwine in a very intri-

cate manner (fig. 12, Plate XIII.), and then crossing in several bundles the anterior grey substance, they reach the commissure in front of the spinal canal, where they decussate by platting with those of the opposite side. Now, when in a transverse and slightly oblique section through the commencement of the pyramids, these fibres were examined with a sufficiently high magnifying-power, I found that they were not prolonged into the anterior fissure and laid as an entirely separate structure along the inner border of the opposite anterior column, but that they plunged into its very substance and became incorporated with it, sometimes near its inner margin, and sometimes more externally. By the extension upwards of this process, the anterior columns, already swollen by the incorporated fibres of the previous decussation, continue to increase in bulk, and project above the level of the olivary columns as two rounded chords. It is known that the outer portion of each pyramid consists of parallel fibres, which are nowhere involved in the decussation, and were supposed by ROSENTHAL to be derived from the lateral column of the same side. These belong to the outer and sometimes deeper portion only of the anterior column, which has not been traversed by the oblique decussating fibres*.

(14.) In addition to the fibres that proceed from the lateral columns and posterior grey substance, there are other decussating fibres that enter into the composition of the anterior pyramids. These are derived from the anterior grey substance, and belong to the system which constitutes the anterior commissure of the *medulla spinalis*. They are less numerous, however, and most distinctly seen at the lower parts of the pyramids (see figs. 11 and 19).

(15.) The anterior pyramids, therefore, are composed of four orders of fibres:—

1. Decussating fibres from the lateral columns, forming their chief bulk.
2. Decussating fibres from the posterior columns and posterior grey substance, particularly at their upper portion.
3. Decussating fibres from the anterior commissure.
4. Non-decussating fibres of the anterior columns, separate on their outer side, and on their inner side incorporated with those that form the decussation.

(16.) Before the fourth month of fœtal life, as TIEDEMANN has well observed†, the pyramids are broad and flat, and have some resemblance, externally, to the pyramidal anterior columns in the *medulla oblongata* of fishes (fig. 1, Plate XII.). At the fifth month they begin to project above the level of the surface, and continue until birth to increase in depth, in consequence of the continual reinforcement they receive from the decussating fibres of the lateral columns chiefly. The decussation may be observed from the fourth to the sixth week. I have repeatedly tried to make transparent sections of the fœtal medulla, but owing to its soft and friable texture, have not succeeded.

* This non-decussating portion of the pyramids is correctly described by Dr. SHARPEY (QUAIN's 'Anatomy') and by Mr. SOLLY (Human Brain) as belonging to the anterior column, but they considered it as the whole of that column.

† Anatomie de Cerveau, traduit par JOURDAN (1823), p. 145.

Received October 22, 1857.

(17.) In Mammalia, the decussating fibres are much less numerous than in Man. Generally, I have found their number to be in the direct ratio of the *prominence*, rather than the *breadth*, of the pyramids. They proceed more from the *deep* strata of the lateral columns, and less from the *superficial* and *anterior*; so that the whole decussation, as will be seen further on, resembles rather the *upper* portion of that in Man (compare fig. 12 with figs. 13, 15, 16 and 17). In the Cat it is stronger than in the Dog, Sheep or Ox, and a transparent section through it presents a very beautiful appearance. A transverse section of the *medulla oblongata* of the *Tiger* bears in every respect a most striking resemblance to that of the Cat: the decussating fibres are numerous, and the anterior pyramids are consequently prominent and deep, so that *relatively to the size of the cerebrum*, they are decidedly *larger* than in Man. In the Guinea Pig also the decussation is well marked, and the fibres it derives from the posterior columns and the grey substance may be very distinctly seen (see fig. 17, Plate XIII.).

(18.) Anatomists are divided in opinion with regard to the existence of the anterior pyramids in Birds, Reptiles and Fishes. Like WILLIS, HALLER, VICQ D'AZYR, DESMOULINS, LEURET and others, I have never seen on the surface of the medulla in birds any distinct pyramidal columns resembling those of the higher animals; but in a transparent transverse section through the point (*i*), fig. 2, Plate XII., at the level of the hypoglossal nerves, a decided decussation may be observed (see fig. 18, Plate XIII.): its fibres, however, are not much more numerous than those of the anterior commissure of the spinal chord, and, like them, are scattered and lost in the substance of the anterior columns. Although, therefore, it cannot be said that distinct pyramidal columns exist in birds, yet LEURET was mistaken, when, in reference to the fibres of their spinal chord, he observed, "D'abord ces fibres ne se croisent pas dans la moëlle allongée, où l'on chercherait vainement une disposition analogue à celle des corps pyramidaux*."

(19.) In Fishes, there appears to be a slight decussation of fibres proceeding from the posterior portions of the medulla, but it is not very distinct.

(20.) The *posterior columns* in Mammalia and in Birds are broad, but shallower than in Man (compare *a*, in figs. 10 and 11, with *a* in figs. 13, 14, 15, 16, 17 and 18). In the Dog, the posterior pyramids have a peculiar shape, each arising from the bottom of the fissure as a thin lamina, which widens towards the surface in the form of a wedge (see fig. 16 *b*).

(21.) As the fibres leave the lateral columns to decussate into the anterior pyramids, the posterior cornua sink, as it were, forwards, and therefore extend more and more towards the sides of the medulla, where their terminal tufts, gradually increasing in bulk, and reaching the surface, form the columns called the grey tubercles of ROLANDO (see fig. 19). At the same time, on each side of, and close to, the posterior median

* Anatomie Comparée du Système Nerveux, tom. 1er, p. 296.

fissure, a small conical eminence may be observed to arise from the posterior border of the central grey mass, from which a network of blood-vessels and radiating fibres extend directly backwards through the posterior pyramid (*b*, figs. 12 and 19). Within the eminence and amongst the network, are developed a number of cells, which for the most part are circular, oval, or pyriform, and give off two processes or more, in both a transverse and longitudinal direction. Fig. 20, Plate XIII., represents them magnified 420 diameters. Each cell contains a distinct nucleus and nucleolus, with a mass of yellow pigment-granules accumulated on one side, or at one extremity. Further outwards, from the root of the *cervix* cornûs, a larger and gradually increasing eminence arises in the same way, and projects through the base of the restiform body, towards the surface of which it sends forth a number of radiating fibres (see *b*, figs. 12 and 19); but its cells, though precisely similar in structure and shape, are superior in size, to those of the former (fig. 21, Plate XIII.). The fibres of both are delicate tubules of small average diameter, and for the most part without double contours. They radiate in tapering and irregular bundles, which interlace with those of the restiform body, where they become longitudinal in part, and are partly continuous at the surface with the superficial layer of arciform fibres.

(22.) These new productions of grey substance will be distinguished respectively as the *post-pyramidal* and *restiform* nuclei, or ganglia. They exist in all the Mammalia, and to a certain extent in Birds. In some of the former animals—in the Cat, for instance,—the restiform nuclei are very largely developed and nearly fill the white column.

(23.) Coincident with these changes, others are taking place towards the sides and front of the medulla; for the anterior cornu becomes gradually divided and subdivided into smaller portions by longitudinal fasciculi of various sizes, around which they mostly communicate (see fig. 11); and from these subdivisions fibres run outwards in great numbers. By the extension of this process, the whole of the cornu is at length resolved into network, which spreads through the lateral column. At the same time the fibres of the network, formerly described as arising from the side of the *posterior cornu* and of the *central grey substance*, continue to increase in number. At first they are crossed, interlaced and very much obscured by those of the decussation proceeding from the bundles enclosed in the meshes which they form; but as the decussation diminishes, the network, still further developed, comes clearly into view, and, in continuity with that of the anterior cornu, appears in the form of a wing with its point directed forwards (see figs. 13, 16 and 19). The network contains a multitude of cells which differ in shape and size. Many are variously fusiform, and appear at intervals in the course of fibres like mere dilatations, which are sometimes exceedingly small; others are oval, triangular, semilunar, or irregular in form, and send out their processes in different directions between the bundles of the lateral column, which they often closely embrace. This arrangement is distinctly seen in Mammalia, Birds, and in Fishes; in the first of these classes the network is rather coarser, and the cells larger and more abundant than in

Man*. Fig. 13, Plate XII. represents a transverse section of the *medulla oblongata* of the Sheep, just below the olivary bodies; and fig. 14, a similar section through their lower ends.

(24.) When nearly the whole of the anterior cornu has become resolved into network, at its root in front of the central canal, a new and gradually increasing column of vesicular substance begins to make its appearance. This is the ganglion or nucleus of the hypoglossal nerve, the lowest fibres of which run out through the remains of the cornu, like roots of the spinal nerves (see fig. 13, Plate XII.). Behind the canal, and on each side, another vesicular column may be observed, at the same time, in process of formation. This is the nucleus or ganglion of *the spinal-accessory nerve*.

(25.) Fig. 23, Plate XIV. represents a transverse section of the human *medulla oblongata*, a little below the olivary bodies†. Here it will be seen that the vesicular mass within the restiform body (*a*) has increased to a considerable extent, and that the network developed in the posterior pyramid (*b*) has spread through the whole of its substance, while the cells in both are multiplied in an equal proportion, and lie scattered at large, or collected into small groups about bundles of longitudinal fibres. The *caput cornûs posterioris*, or *tuberculo cinereo*, also (*f*), has enlarged its dimensions, and is now crowded with cells, of which some are exceedingly small; they are similar, in structure and shape, to those in the posterior columns, and, like them, are connected with a number of fibres which they appear to generate from their processes. The central canal is more or less pervious, but generally compressed at the sides, sometimes to a mere line. It is lined with a very distinct layer of columnar epithelium, like that which I first pointed out in the spinal chord‡. Behind it on each side is the commencement of the *spinal-accessory nucleus*, the cells of which, apparently in different states of development, are pyriform, round, triangular or variously fusiform: they are mostly pale and exceedingly delicate, but many are partially or entirely filled with granules of yellow or dark brown pigment: this is especially the case with the fusiform variety, which are frequently ranged in linear series by the junction of their processes, which would seem to be forming into nerve-fibres. Between the posterior parts of the

* I am inclined to think that some of the smallest of these cells belong to connective and fibrous tissue. In every part of the grey substance of the spinal chord they are also very abundant, and often resemble exactly the formative cells of elastic tissue.

† I have chosen this part for an enlarged representation, because it is the point where nearly all the most important changes in the structure of the medulla are seen at the same time, and in close connexion with each other. The details were observed under powers varying from 150 to 420 diameters, without any pressure or displacement whatever.

‡ It is stated by STILLING, in his new work on the spinal chord (Neue Untersuchungen, Erste Lieferung, p. 20), that I was directed by BOWMAN to the discovery of these cells. This is a mistake, but one, perhaps, which might not unreasonably follow from the wording of my own note (Philosophical Transactions, 1851, Part II. p. 614). However, the fact is, that having observed this structure around the spinal canal, without deciding on its nature, I pointed it out to Mr. BOWMAN, who *then* suggested that, perhaps, it was epithelium, which on *further* examination in a perfectly fresh state, I found to be the case.

spinal-accessory nuclei, at the bottom of the median fissure, is a transverse commissural band divided on each side by a longitudinal column into two portions, which again unite, and becoming continuous with cells, either single or in linear series, run partly behind and partly through the nucleus and network in the lateral column as fibres of the accessory nerve. In front of the canal are the first-formed cells of the *hypoglossal nucleus*; and a little further forward is the *non*-decussating portion (I) of the anterior pyramid, consisting of that outer and deep part of the anterior column at the side of the sulcus (I, figs. 11, 12 and 19) which remained unmixed with the decussating bundles from the opposite lateral column, but is now crossed at its posterior half by those of its own side, which divide it into smaller fasciculi. The anterior cornu which lay on its outer side is wholly resolved into network (represented in the left half of the figure 23); but amongst this network (omitted on the right side) may still be observed a number of small fusiform cells, sometimes pigmentary, and joined in linear series; and with these are a few others that are larger, oval, fusiform and triangular, and lie mostly with their longer axes and processes parallel with a multitude of fine fibres, which running obliquely outwards, in part form the roots of the hypoglossal nerve. Traced backwards, these fibres are found to have various destinations. Some of the innermost layer bend forward round the root of the pyramid and join in the decussation; a few run obliquely backwards round the opposite side of the canal, in front of which they first decussate with their opposite fellows, and become continuous with cells that are often darkened by pigment; the rest take their origin from the cells of the nucleus. Scattered in part amongst these fibres, and partly resting in masses on the back of the pyramid, is a multitude of cells much smaller than the rest, which form the commencement of the olivary lamina. In the posterior part of the lateral column, amongst the network in front of the *caput cornûs posterioris*, is seen a remarkable group of large stellate, pyriform and fusiform cells (*p*), which send out their processes to a great length between the longitudinal bundles enclosed in the meshes; and nearer the anterior and outer part of the same column is another curious group (*g*), to be described further on. The decussation of the anterior pyramids, though still considerable, is very much reduced; for the fibres it derives from the lateral columns, which at first were its principal source, have become comparatively few, while those that proceed from the posterior columns and central grey substance have been gradually increasing in number, though not in a corresponding inverse proportion. From before backwards the decussating bundles may be traced round the sides of the central canal, where the fibres of each spread out and interlace with the rest in a series of curves and undulations. Some are continuous with the deep longitudinal bundles of the lateral columns; others run outwards to the plexus or network at the root or base of the *caput cornûs posterioris*; the rest extend backwards, and of these, some wander amongst and end in the cells of the central grey substance, while others are prolonged through the posterior columns.

Of the Corpora Olivaria.

(26.) The *corpora olivaria* were first made known by EUSTACHIUS in his eighteenth plate, and were so named by VIEUSSENS. Although denied by ROLANDO, LEURET, LONGET and some others, they are certainly found not only in Mammalia, but even to a certain extent in Birds; but differ somewhat in form. In Man they are larger than in any of the inferior animals, except the Elephant; and next in dimensions are those of the Ape-tribe and Cetacea (Dolphin and Porpoise).

(27.) *Structure.*—In Man each corpus olivare is separated from the pons by a deep depression, which in animals is occupied by a broad band called the *trapezium* (see figs. 3, 4, 7, 9). Its surface consists of two layers of fibres, transverse and longitudinal: the former belong to the arciform system, the latter are continuous with the antero-lateral column on the outer side of the pyramid. It is well known, that in a transverse section, the *corpus dentatum*, or grey substance of the olive, appears in the form of a convoluted lamina reflected upon itself at the surface, or like the longitudinal section of a sac placed transversely and somewhat obliquely with its mouth near the raphè and its fundus at the surface (see figs. 28 *et seq.*, Plate XVI.). In such a section the folds of the lamina are more or less at right angles to its course; but in sections made longitudinally and in intermediate directions they are seen to be prolonged sideways, and to be continuous with others in different planes and at various angles; so that the entire area of the sac is unequally and diversely undulated. Fig. 24, Plate XV. represents a longitudinal section with part of the olivary (white) column. Here the convolutions are seen to bear a striking resemblance to those of the cerebral hemispheres, for they are formed on the same plan; and, like them, the vesicular sac encloses a white nucleus of fine tubular fibres, which have the same kind of relation to its folds as the central fibres of the hemispheres have to *their* convolutions; and further, it is joined to its fellow of the opposite side by a transverse commissure, consisting of separate bundles, which communicate, however, and cross the raphè behind the anterior fissure (figs. 30, 31, 32). The average thickness of the lamina is about $\frac{1}{80}$th of an inch. Its cells are of small but rather uniform size, and measure from $\frac{1}{1800}$th to the $\frac{1}{1000}$th of an inch in diameter; but in shape they vary from the globular to the oval, the pyriform, the prismatic, and the semilunar, according, apparently, to the number, relative distance and direction of their processes: these are generally numerous: I have seen as many as eight proceeding from one cell: they extend in different directions, transverse, longitudinal and oblique, and are broad at their origin, but frequently taper rapidly like a short spur, or divide abruptly into several branches, which become continuous with the nerve-fibres (see fig. 22, Plate XIII., and fig. 25, Plate XV.). Each cell encloses a large globular or elliptical nucleus, containing a very distinct nucleolus.

(28.) Behind the olivary sac is a separate elongated mass composed of the same kind of cells; and a similar but larger mass (broken into parts by bundles of the deep arciform fibres) is found in front of the lamina, near the side of the raphè. The former

is called by STILLING the accessory olivary nucleus, and the latter, the large nucleus of the pyramid. I believe they are both parts of the olivary folds.

(29.) As may be seen in fig. 23, Plate XIV., it is amongst the network into which the anterior cornu is resolved, and through the outer portion of the anterior column by which it was surrounded, that the olivary body is developed. Immediately below the inferior rounded extremity of the olive, the cells are not arranged in the form of a convolution, but scattered at large (fig. 24, Plate XV.). Many of them are elongated also in the direction of the column and are distinctly continuous with some of its fibres; but the *bundles* of fibres pass on to the sac and diverge (see fig. 24, Plate XV.). The superficial layer bends forwards and outwards, and running longitudinally along the surface, sends some of its fibres in succession between the outer convolutions of the lamina, and then proceeds onwards through the pons; the bundles of the deep layer spread out in the olive, passing through and between the remaining convolutions, and forming a large portion of the central nucleus. In relation to the lamina, the course and arrangement of the fibres of the sac are very complicated, and not easily described with perspicuity*. Fig. 25, Plate XV. represents a series of convolutions from the posterior wall of the sac, with part of the central nucleus (O, O), as seen in a transverse section. The convolutions are turned with their convexities alternately *towards* and *from* the nucleus or interior of the sac, and the concavity of each is occupied by a bundle or process of fine tubular fibres, which diverge within it. The *bundles*, then, are alternately *within* and *without* the cavity of the sac, but a great many fibres of the one set are continuous with those of the other through the vesicular lamina or wall. They assume the form of the convolutions, and sometimes divide into two or three branches, which receive convolutions between them. For convenience of description, the fibres of each bundle may be divided into two sets. On selecting an inner bundle (P) or process of the central nucleus (O), it may be seen,—1st, that the fibres at its centre or axis proceed in straight lines nearly to the summit of the convolution, where some of them terminate in cells of the lamina, and some form a series of curves or tortuous loops between them; while others pass through the lamina either singly or in small bundles, and cross each other in a tortuous course towards the posterior part of the medulla (Q). 2ndly. The lateral fibres of the bundle are successively more divergent towards its base: some of them terminate in cells; but the rest in large numbers pass through the lamina to the next *outer* and *inverted* bundle on each side, from the bases of which they partly turn round the summit of the convolution to form a band of some depth, and partly diverge to the posterior region of the medulla (Q), where they cross each other with different degrees of obliquity and join the arciform plexus (see fig. 36, Plate XVII. x''). Traced towards the interior of the sac, the fibres near the *middle* or axis of the bundle (P) diverge through the nucleus (O, O), while those at the *side* of its base turn round the extremity of the next convolution (R) to be continuous with the *nearer* side of the next inner

* It has cost me extraordinary time and trouble to arrive at a satisfactory conclusion on this very difficult point; and I succeeded only by a still further modification of my method.

bundle (P′), and through the lamina, with the *further* side of the outer and intervening bundle (Q′); and so on through the rest of the lamina; but although these latter fibres appear to follow the course of the convolutions, I think that at intervals they terminate in cells. At the antero-lateral parts of the sac, the axial fibres of the *outer* bundles form the crust of the olive (see figs. 28 *et seq.*, Plate XVI.), and are continuous, on the one hand, with longitudinal fibres of the olivary column, and on the other hand, with the transverse olivary commissure and the system of arciform fibres. On the left side of fig. 25, Plate XV., the cells of the lamina are faithfully represented *in situ*, and in connexion some of the fibres. The olivary bodies, then, are intimately connected with all the surrounding parts of the medulla, chiefly through the arciform system, as will be more fully shown further on; but I have never been able to trace any immediate connexion between the cells of the lamina and the roots of the nerves,—not even of the hypoglossal nerves which pass directly through it. It is probable, therefore, that the *olivary bodies* are coordinating centres for the different ganglia or nuclei of the *medulla oblongata*.

(30.) The description thus given of the course of these fibres appears to be highly important, not only in reference to the structure of the olive, but on account also of the light it would seem to throw on the structure of the cerebral hemisphere; for since in both these organs the convolutions are formed on precisely the same plan, and have precisely the same relation to the *bundles* proceeding from the *nucleus*, it is highly probable that the *fibres* of these bundles, in both cases, have the same destination and course; indeed something of the kind in the cerebral convolutions has been already made out by more than one observer. The existence of the *outer* bundles connecting the olive with distant parts does not interfere with the comparison.

Received November 19, 1857.

Corpora Olivaria of Mammalia and Birds.

(31.) While in Mammalia the actual existence of the olivary bodies is denied by many anatomists, to those who admit them, their form, structure, and connexions may be considered as unknown. I shall therefore describe them in one or two animals of this class.

(32.) In the *Simiadæ*, the olivary bodies are prominent at the surface, but vary somewhat in size and shape in different genera. In *Cercopithecus* and *Semnopithecus* (figs. 38 and 39, Plate XVII.) they are more or less oval; while in the *Wanderoo* (fig. 40), they are more semilunar, as in the *Bear* and *Seal* (fig. 41). Figs. 7 and 8, Plate XII. represent side views of the *medulla oblongata* of the *Sheep*, and figs. 3 and 4 exhibit front views of the medullæ of the *Cat* and *Dog*, with parts of the cerebrum and cerebellum. As it ascends from the points of the anterior pyramids, the *medulla oblongata* becomes much enlarged, and rather suddenly forms in front a projection which varies in extent in different animals. At the base of the pyramids and the lower border of the *pons* is a

broad band, called the *trapezium* or inferior *pons* (*s*), which in the *Cat* and other animals of the feline species is very prominent on each side*. Along the outer border of the pyramid is a narrow column, which is not so distinct in some animals. This is the *olivary* column as it appears at the surface. It bears near its middle a prominent mass, which is oval and small in the *Sheep* and *Cat*, but semilunar and larger in some animals, as the *Bear* and *Seal*. In the *Tiger* it resembles that of the *Cat*, and forms a long and somewhat crescentic band, the curve of the crescent embracing a corresponding convexity along the outer side of the pyramid. At its upper end, as may be seen in figs. 7 and 8, it sinks behind the pyramid, but is continuous, *below*, with a distinct but slender fasciculus (*h*) of the antero-lateral column. In the figures, the dots along its inner border indicate the attachment of the hypoglossal nerve. At (*i*) on each side, the anterior pyramid commences, and suddenly projects forward as an oblong swelling, which might be mistaken for an enlargement of the pyramid itself. But if a transverse section (fig. 14, Plate XII.) be made through the lower part of the protuberance, it may be seen that the decussation has already ceased, and is therefore very limited in extent. The pyramids (*i*, *i*) are consequently very shallow, but rendered prominent by the olivary bodies, which are chiefly imbedded behind them, and appear at the surface as a narrow column only. As in Man, each of these bodies consists of a vesicular sac enclosing a central nucleus; but the convolutions of the lamina are fewer and comparatively larger, as may be seen in fig. 26, Plate XV., which represents a transverse section through the middle of the protuberance of the medulla of the Sheep, in a plane passing through the point of the *calamus scriptorius*. It rests in a concavity of the pyramid, with one extremity at the side of the raphè. The opposite bodies are united by a transverse commissure, composed of separate bundles which undulate through them into the lateral columns to be continuous with the arciform system: immediately behind the pyramids some of these fibres form a very regular and wavy band. Fig. 27, Plate XV. represents a transverse section of the olivary bodies and pyramids in the Cat; those of the Guinea Pig are seen in fig. 17, Plate XIII., resting on the back of the pyramids. In the Simiadæ, the vesicular lamina, or *corpus dentatum*, is thrown into numerous convolutions, and has nearly the same shape and appearance as in Man.

(33.) The cells of the lamina vary somewhat in different orders. In the Ox, Sheep and Cat, they are about equal to those of Man, but many are more elongated. In the Guinea Pig they are not so large.

(34.) In Birds the cells are small and not arranged in a lamina, but scattered through the side of the anterior column (see fig. 18, Plate XIII.).

(35.) On the outer side of each olivary body, and separated from it by a groove which lodges the hypoglossal nerve, is another vesicular column of nearly the same length, but broader externally. It is rather cylindrical in the Cat (fig. 4, Plate XII.), fusiform in the Sheep (figs. 7 and 8), and in the Dog forms a broad swelling at its lower extremity.

* The *trapezium* is found in all the Simiadæ except the Chimpanzee, but varies in size, and is generally sunk deeply at the side of the olive.

Above, it blends as a flattened band with the trapezium, close to the origin of the facial nerve, which arises from the side of the latter (fig. 8); and below, it is continuous with a distinct fasciculus of the lateral column (*q*). From its side and that of the olivary body, the broad band of arciform fibres crosses the medulla to reach the posterior columns; but within, it is traversed by a network or plexus, formed by the interlacement of these fibres with those remaining from the anterior cornu, and enclosing the longitudinal bundles of the lateral column. Amongst this network lie the cells, which are larger than those of the olivary body and more irregular in shape. They are oval in different degrees, or pyriform, fusiform, crescentic, club-shaped, triangular, or variously stellate, and give off processes which nearly encircle the longitudinal bundles, and contribute to form the meshes. All these appearances may be very distinctly observed in the Sheep, Ox, or Cat.

(36.) In Man a similar structure was found, but owing to the difference in the shape of the medulla, it lies behind, instead of at the side, of the olivary bodies, and is not so prominent externally (see figs. 23 and 28 *g*): the cells also are rather less than those of the Mammalia.

FRA NS LIBRAR

Of the Structural Changes in the upper part of the Medulla.

(37.) Through the lower fourth of the olivary bodies, the decussation diminishes in breadth, and at length becomes the raphè, the fibres of which are connected chiefly with the borders of the pyramids as part of the arciform system. But now there begins to be developed within the pyramids themselves, a new vesicular system, which increases as it ascends, and forms the chief part of the grey substance of the *pons Varolii*. Each pyramid in front and at its sides is pierced by blood-vessels of considerable size. One of these enters from the anterior sulcus, and running posteriorly, sends off from its side across the back of the pyramid a number of nearly horizontal branches, which communicate with those of another vessel that enters through the fissure on its outer side in front of the olivary body, as well as with each other by lateral branches and with those that enter in front of the pyramid. The transverse network at the back of the latter contains a number of scattered cells, which are small, but uniform in size, nucleated, and pigmentary; in shape they are oval, pyriform, more or less triangular, or very long and fusiform; they send out processes which either encircle the longitudinal bundles, or run along the small fissures towards the sides of the pyramid; so that they form a complete network of nearly single fibres. But at the inner side of the pyramid, near the bottom of the anterior sulcus and against the arciform fibres where they are continuous with the raphè, in the process of pia mater round the artery and its first branches from which the transverse network proceeds, there is formed a large vesicular mass (see A, fig. 36, Plate XVII.), which sends out tapering or pointed prolongations across the back of the pyramid, where the processes of their cells become continuous with those of the network just described; but the cells at the base of the mass are turned with their longer axes in the direction of the course of the arciform fibres, against which they

lie, and with some of which they are certainly continuous. Around the front of the pyramid there are several other more or less triangular masses of the same kind (A′), that send backwards a number of similar prolongations, from the cells of which a multitude of fibres radiate through the pyramid and partly disappear, probably to become longitudinal. Between these prolongations some of the fibres form loops within the border of the masses; and between the masses themselves, fibres proceeding from the substance of the pyramid run outwards to the arciform band at the surface, where they turn right and left, and form a series of loops by re-entering at different parts.

(38.) These vesicular masses, therefore, appear to generate new fibres in the pyramids, and new arciform fibres, the latter of which not only connect together different parts of the pyramids themselves, but, as we shall see further on, the system to which they belong establishes the most intimate communication between *all* parts of the medulla.

(39.) The *hypoglossal* and *spinal-accessory* nuclei continue to increase as they ascend, until, by the divergence and diminution of the posterior pyramids, they are exposed on the surface of the fourth ventricle. The first or *hypoglossal* consist of two cylindrical columns, which are separated from each other by the raphè, and situate at first in front and at the sides of the canal (see *t*, figs. 23, 28, 29, 30, 31, 32, 33). They contain a great number of oval, pyriform, fusiform and stellate cells, of large size, and precisely similar to those of the anterior cornu, and are surrounded on their outer sides by the network of the lateral column, which, as already shown, is also studded with cells of all shapes and dimensions. The processes of the hypoglossal cells are both longitudinal and transverse: of the latter kind (fig. 35, Plate XVII.), some extend backwards towards the spinal-accessory nucleus; others towards the raphè, with the fibres of which they are sometimes continuous; a third set run outwards, and escape through the network of the lateral column, as do those of the anterior cornu of the *medulla spinalis*; but the greater number are continuous in front with the fibres of their own nerve.

(40.) In Mammalia generally the nucleus and cells have nearly the same appearance as in Man. In Birds the nucleus is rather more posterior, and its cells are smaller, but in other respects similar (see fig. 18).

(41.) The *spinal-accessory* nucleus on each side is developed in great part from the posterior and lateral portion of the central grey substance. It appears at first as a narrow tract (*r*, fig. 28, Plate XVI.), which extends from the bottom of the posterior fissure, obliquely outwards and forwards, along the side of the canal, over which, with its opposite fellow, it forms a kind of slanting roof. It is overlaid by the root of the posterior pyramid, from which it is afterwards partly developed, and rests, as it extends forwards, on the back of the hypoglossal nucleus. Its anterior extremity divides into two portions or horns, which partially enclose some longitudinal bundles of the lateral column, and are continuous with the roots of its nerve. As the nucleus ascends the medulla, its posterior portion enlarges at the expense of the posterior pyramid, on the base and inner side of which it gradually encroaches. The majority of its cells are oval, pyriform or fusiform, and turned with their longer axes in the direction of the nerve;

they lie chiefly in the inner portion of the nucleus, contain distinct nuclei, and are remarkable for their transparency, which gives to the ganglion a peculiar, pearly aspect; but some, towards its outer extremity, are filled with dark brown or blood-red pigment-granules, and contain no nuclei (see fig. 23).

(42.) In Mammalia the form and colour of the ganglion are nearly the same as in Man; but the cells are larger, more elongated and less delicate, and none of them are filled with pigment-granules, as in the human medulla.

(43.) Like the vesicular columns just described, the *postpyramidal* and *restiform* ganglia continue to increase as they ascend, and by their lateral extension form nearly one continuous mass on each side of the medulla (fig. 28 *et seq.* Plate XVI.). The cells of the former spread through the whole of the pyramid, and are most numerous near the surface. In the superficial portion of the restiform body the interlacement of its own fibres with those radiating from its grey substance is extremely intricate (see fig. 36); it is loose and irregular, like that of a sponge, and contains in its interspaces a variable number of cells, which send out their processes to be continuous with fibres in all directions.

(44.) Figs. 23, 28, 29, 30, 31, 32 and 36, Plates XVI., XVII., represent a series of transverse sections, from the lower ends of the olivary bodies to the fourth ventricle. The *caput cornûs posterioris* is pierced at its root by longitudinal bundles, enclosed in the meshes of a plexus of the deep arciform fibres which proceed from the posterior columns (figs. 32 and 36). These longitudinal bundles are exceedingly interesting, for I have traced the continuity of some with the descending root of the trifacial nerve: in the angular spaces around them cells are imbedded, and between them the roots of the vagus and glossopharyngeal nerves proceed inwards to their ganglia.

(45.) The ganglia or nuclei of the *par vagum* commence with the fourth ventricle, and are directly continuous with the vesicular columns from which the accessory nerves take their origin. These vesicular columns, by encroaching on the bases and inner sides of the posterior pyramids, gradually rise to the surface, and diverging to form the point of the *calamus scriptorius*, enlarge into two pyriform masses along the inner border of the pyramid, from which they are partly developed * (*rr*, fig. 5, Plate XII.). Each has the same form as the spinal-accessory nucleus, and in the same way, its deeper portion, which lies beneath the pyramid, is divided into two horns by longitudinal bundles of the lateral column (see *r*, figs. 29, 30, 31, Plate XVI.). Its cells also are similar to those of the accessory nucleus, but more abundant (see fig. 37, Plate XVII.). I can find no other difference. At the point of the *calamus scriptorius* the two nuclei are joined by the upper

* These pyriform bodies are represented in GALL's plates, but were first described by ROLANDO as a portion of the central grey substance:—"Ces tubercules ne sont rien autre qu'une portion de la substance cendrée renfermée dans la moëlle épinière et la moëlle allongée, qu'on peut suivre vers le haut, jusqu'au quatrième ventricule, où elle se montre sous la forme de deux feuilles lancéolées de substance cendrée."—Recherches Anatomiques sur la Moëlle Allongée, 4to, p. 22. STILLING, however, has the merit of having first shown them to be the nuclei of the par vagum.

border of the transverse commissure, which forms the roof of the central canal. Beyond this point, therefore, the canal is laid open and expanded into the fourth ventricle, in the floor of which the vesicular column or nucleus of the *hypoglossal* nerve ascends on each side of the mesial line (see fig. 5, Plate XII.). Fig. 33, Plate XVI. represents a transverse section of the medulla of the Sheep at the point of the calamus scriptorius, where the transverse commissure bridges over the upper extremity of the canal. A similar section of the human medulla is represented in fig. 29, Plate XVI., where the commissure is broken and the canal laid open. Fig. 30 represents another transverse section about two lines higher up (between the points *a* and *r* in fig. 5, Plate XII.), in which the hypoglossal nuclei (*t*) are seen in the floor of the fourth ventricle. Near this point, the divergent extremities of the pyriform *vagal* nuclei *appear* to terminate abruptly; but in a transverse section, immediately beyond them, they are found to sink beneath two new masses of vesicular substance—the auditory ganglia (*v*, figs. 31, 32, 36) —which now begin to make their appearance at the sides of the medulla, and to which, in part, they appear to contribute. Here they gradually diminish, and become one of the nuclei or centres of origin of the glossopharyngeal nerves. At the last or highest roots of these nerves, which adjoin the anterior division of the auditory, there remains but a small group of their peculiar oval cells, to which separate divisions of the nerves find their way; while the rest of each nucleus becomes so gradually blended with the lower angle of the auditory ganglion, as not to be distinguished from it.

(46.) The arciform fibres which connect together the anterior and posterior portions of the medulla and its two lateral halves, are very numerous, and extremely intricate in their course and arrangement. They have been divided into two layers, *superficial* and *deep*; but both these layers are continuous, or intimately connected with each other at different points. The course of the superficial fibres has been already described (§ 5 and 6). At the back of the medulla they issue from the posterior columns, but chiefly from the restiform nucleus, and are then collected into a broad band (*x*, fig. 36, Plate XVII.), which proceeds transversely over the surface of the gelatinous substance. On reaching the lateral column they separate into bundles, which join the deep set and reunite with each other to form a plexus through the column of cells at the back of the olivary body (*g'*, figs. 29 and 32, Plate XVI.). The remaining fibres of the band advance round the surface of the olive and front of the pyramid to the anterior sulcus, as already stated.

(47.) The deep layer of arciform fibres may be said to arise, posteriorly, from the *post-pyramidal* and *restiform* ganglia, in which they are partly continuous with the superficial layer, either directly or through the medium of cells (figs. 31, 32, 33, 36). Collecting into bundles that join in an intricate plexus, they traverse first the *caput cornûs posterioris*, in which, with the horizontal roots of the *vagus* and *glossopharyngeal* nerves, they again interlace around the longitudinal fasciculi which ascend, as already stated, to the large root of the trifacial nerve. On arriving at the lateral column, the plexus expands through its whole breadth, but may be described in two parts.—the *lateral*

and the *deep*. The *lateral* portion, in front of the *caput cornûs*, communicates freely, as above described, with the superficial layer, and then sends forward a series of bundles that traverse and surround the *olivary body*. Its *outer* bundles (y) sweep round the front of the sac, and having sent in their course some fibres between its convolutions and into the white nucleus, they separate behind the pyramid into a series of other bundles which are gradually larger from before backwards, and communicate to form a small plexus, of which the finer or anterior portion, containing some cells, proceeds inwards and forwards through the pyramid to the vesicular nuclei (A, A′) along its border, while the coarser and posterior portion is continuous with the transverse olivary commissure. The *inner* bundles (x'') of the *lateral* plexus pierce the olive from behind, and winding through different parts of its substance, join the fibres of the white nucleus,—those internally at an angle,—and then proceed with them to form the principal part of the transverse commissure. The bundles of this commissure thus formed communicate with each other by lateral branches, as a plexus, and proceed to the edge of the raphè behind the anterior sulcus. Here they diverge and decussate freely in such a manner, that each exchanges fibres with *several* others of the *opposite* side that lie at different depths of the commissure, while the most divergent fibres from the *anterior* side of each bundle decussate to be continuous with the arciform band which runs round the opposite pyramid (see fig. 36 B).

(48.) The *deep* portion of the plexus from the lateral column, directly continuous with the other, or *olivary* portion, sweeps inwards to the remaining posterior part of the raphè, its main bundles curving backwards and becoming shorter as they approach the posterior surface (see figs. 29 and 30, Plate XVI.). Across the raphè they all diverge (see fig. 34, Plate XVII.), and like those of the olivary commissure, exchange fibres with bundles of the opposite side at a distance corresponding to their divergence, the central fibres of each crossing nearly in straight lines. Many of the most divergent, on reaching the opposite side, take an antero-posterior direction along the raphè, passing out singly and at intervals into different parts of the plexus and the longitudinal fasciculi enclosed in its meshes. At the summit of the medulla, the number of antero-posterior fibres is very much increased by considerable bands, which, proceeding from the auditory ganglia, and decussating at acute angles as they enter the raphè, run down it parallel to each other; and these bands at their decussation are crossed by that of two other bundles proceeding from the centre of the lateral columns and the remains of the glossopharyngeal nucleus (fig. 36, Plate XVII.).

(49.) The *raphè*, therefore, is the seat of a wonderfully complicated decussation between fibres from all parts of the *opposite* halves of the medulla, chiefly through the system of arciform fibres, which at the same time connect together all the parts of each *separate* half. The arciform plexus is everywhere interspersed with circular, oval, pyriform, fusiform, triangular or stellate cells, of different sizes, which give origin to some of its fibres, and frequently lie against the longitudinal fasciculi, with the fibres of which they are *probably* also continuous, for many of their processes run in the same direction.

Most of them contain a variable number of dark brown or blood-red pigment-granules. At the summit of the medulla, the raphè contains some oval and fusiform cells, lying with their longer axes parallel to it, and continuous with its fibres; and along each of its borders others of a similar kind are so numerous, that they form at intervals strata of considerable depth (see fig. 31, Plate XVI.).

Origin of the Nerves of the Medulla oblongata.

(50.) *Of the Spinal-accessory Nerve.*—It is well known that this nerve arises from the lateral column as low down as the sixth or seventh cervical vertebra. Its lowest rootlets, which are very delicate, may be traced to the lower part of the cervical enlargement, where they come off from the verge of the posterior-lateral fissure in company with the posterior roots of the spinal nerves; but its upper rootlets are attached in an irregular manner to nearly all the posterior half of the lateral column. At the lower part of the *medulla oblongata*, several large bundles proceed directly inwards to the side of the grey substance, midway between the anterior and posterior cornua, or a little below the level of the central canal. Here they bend forwards nearly at right angles into the anterior cornua, where their fibres separate and mingle with those of the anterior roots amongst the group cells (see g'', fig. 11, Plate XIII.). Higher up, even to the end of the pyramidal decussation, similar bundles may be seen, taking the same course forwards through the remains of the anterior cornu (fig. 19, Plate XV.). At the point where they bend round, there exists in animals a peculiar separate group of cells, of considerable size, which send their processes outwards to the lateral column. In Man, the whole lateral portion of the grey substance is filled with oval, pyriform, circular and fusiform cells, which are more or less pigmentary, of small average size, and lie thickly scattered, or at least are not collected into isolated groups. Some of these cells extend behind and at the side of the canal, and contribute to form the central nucleus of the accessory nerve. Towards this nucleus the remaining upper roots of the nerve proceed obliquely inwards and backwards (g'', fig. 28). The majority of their fibres are continuous with its cells, but some form a series or band of loops around the small mass of longitudinal fasciculi that separates its two horns: one bundle turns *inwards*, and after sending successively *forwards* a number of single fibres through the lateral network into which the anterior cornu is resolved, winds in front of the hypoglossal nucleus, and crossing the hypoglossal nerve, decussates with its fellow of the opposite side. These latter fibres are not so distinctly observable in Man as in some of the lower animals, for they are more delicate, less numerous, and, moreover, are obscured by the still decussating bundles of the anterior pyramids; but in the Ox, and particularly in the Sheep, they may be seen in the most satisfactory manner by means of a sufficiently-high power, and some of them may be traced even to the cells of the hypoglossal nucleus, where apparently they also form loops of continuation with the fibres of the hypoglossal nerve.

(51.) Collins, Malacarne, Vicq D'Azyr, Cuvier, Tiedemann and others, were unable to find any separate *spinal-accessory* nerve in birds; but Serres states that he has found

it in the Cassowary, the Ostrich, and the White Stork (*Ardea ciconia*), and that it joins the *vagus*, after ascending from the level of the posterior roots of the fourth spinal nerve*. In the domestic Fowl and some other birds, I have seen this nerve taking a similar course on the surface of the medulla; and in transverse sections of the *medulla oblongata* of the Ostrich, I have distinctly traced its roots through the lateral columns to their vesicular nucleus on each side, and a little behind the central canal. In many preparations which I have by me, the cells of this nucleus are beautifully shown.

(52.) *The Hypoglossal Nerve.*—In Man this nerve is attached to the surface of the medulla, along the *inner side* of the olivary body, between it and the pyramid; but in Mammalia, generally, it lies on its *outer* side, and in Quadrumana (the *Simiadæ*) it is attached to the olive itself, as is also the case in certain other animals in which that body is large. This diversity in the place of attachment of the hypoglossal nerve results from the difference in size of both the pyramids and olives in different animals; for where both these are small, there is ample room for the olive on the inner side of the nerve behind the pyramid; but where both are large, as in Man, the space internal to the nerve is occupied entirely by the pyramid, while the olive swells out beyond it. The nerve, in Man, proceeds inwards in several bundles, which wind at first in a sigmoid or serpentine manner through different parts of the olive, and then pass backwards, in nearly straight lines, to the nucleus in front of the central canal. Here their fibres diverge and cross each other in every direction (see fig. 35, Plate XVII.). Many are certainly continuous with processes of the cells; some turn outwards and run through the network between the bundles of the lateral columns, as do the anterior roots of the spinal nerves; others bend inwards and decussate through the raphè with their opposite fellows; while the rest pass backwards through their own nucleus to that of the accessory nerve. A similar course is observable in the Ox and Sheep.

(53.) In Birds the course of the hypoglossal roots is very peculiar. Proceeding inwards for a short distance, their fibres separate, and form, with the processes of cells and the longitudinal fibres of the white columns, an intricate plexus or network, on their way to their nucleus.

(54.) *Of the Vagus Nerve.*—The *vagus* nerve commences near the point of the *calamus scriptorius*. On their way inwards, its roots traverse, in several bundles, the gelatinous substance, and cross the plexus proceeding from the posterior columns, enclosing with it the longitudinal fasciculi which ascend to the large root of the trigeminus. They are therefore more horizontal in their course than those of the accessory nerve which runs in front of the gelatinous substance, but their fibres are distributed in nearly the same way; for some are continuous with the cells of the nucleus; others form loops around the group of longitudinal fasciculi between its two horns; while a *separate* bundle turns *inwards*, and after sending forwards in succession a number of single returning fibres, which wander through the network of the lateral column, proceeds through the side of the hypoglossal nucleus, where its fibres mingle with those of the hypoglossal

* Anatomie Comparée du Cerveau, tom. iᵉʳ. p. 502. and planche iv.

nerve,—I may almost affirm that some at least are continuous with the cells. Such is the course I have repeatedly observed in Man; and in the Sheep and Ox I can show, without any difficulty, that while some of the fibres of the last-mentioned *inner* bundle are apparently continuous with those of the hypoglossal nerve, others pass inwards to decussate through the raphè.

(55.) In Birds, since the posterior columns are comparatively shallow, and the gelatinous substance is consequently less advanced, the vagus nerve is on a level posterior to that in Mammalia, but its course within the medulla is nearly the same; for the separate origin of its fibres from its own nucleus and that of the hypoglossal nerve, as well as their decussation in front of the canal, are very distinctly and beautifully seen.

(56.) It has been already shown, that the vesicular column that gives origin to the accessory nerve, after reaching the surface of the fourth ventricle as the nucleus of the vagus, sinks beneath the auditory ganglion, and diminishing in size, becomes part of the nucleus of the glossopharyngeal nerve. Fig. 36, Plate XVII. represents exactly a transverse section of one-half of the human medulla at the uppermost roots of the vagus nerve (D). (*a*) is the restiform body; (*v*) the commencement of the *auditory ganglion*, formed out of the summit of the posterior pyramid, and apparently of part of the vagal nucleus; (*b*) is the deep portion of the posterior pyramid thrown aside and blending with the restiform body: it is traversed by a network of fibres, proceeding from the ganglion of the *portio mollis* (*v*) and containing a number of cells, which send out their processes between the longitudinal bundles represented by the dark spots; this network gives origin to the anterior or inferior division of the *auditory* nerve; (*r*) overlaid by the ganglion of the *portio mollis*, and partly blended with it, is the remainder of the nucleus of the vagus nerve, enclosing at its outer extremity its group of longitudinal bundles, which now adjoin those in the deep portion of the posterior pyramid; through the outer part of the nucleus, a number of fine fibres, proceeding from the network (*b*) in the posterior pyramid and across the ganglion of the *portio mollis*, extend inwards to the network in the lateral column; and around the head or inner extremity of the vagal nucleus, another band of fibres, issuing from the ganglion of the *portio mollis*, proceeds likewise to the lateral column; (*f*) is the extremity of the posterior cornu, pierced by longitudinal fasciculi and crossed by the deep plexus of arciform fibres proceeding from the posterior pyramid and the restiform body; along its inner or anterior margin (*l*) a bundle of fibres and a blood-vessel extends forwards and outwards through the lateral column, and more internally are two or three others, running in the same direction; (*t*) is the floor of the fourth ventricle; it is continuous with that of the central canal, and is likewise lined with columnar epithelium, which rests on a layer of fine fibres. Beneath the latter is another layer of fibres (*t'*), interspersed on each side, and partly continuous, with a number of oval cells, which lie with their longer axes parallel to them; in their course inwards the fibres run down the side of the raphè (*t''*), and in the opposite direction they extend round the surface of the auditory ganglion. Immediately beneath this layer, and resting on the inner part of the antero-lateral column, is the continuation

of the vesicular nucleus of the hypoglossal nerve, or the commencement of the *fasciculus teres*, from which, higher up, the *facial* and the *abducens* or sixth nerve have a common origin: it is filled with cells, which vary considerably in size, and are smaller than those of the hypoglossal nucleus: those nearest the raphè are the largest, and mostly oval or spherical. Proceeding from the front of this nucleus are two or three considerable bundles of fibres and several smaller ones, which run forwards and take nearly the same course as the hypoglossal nerves towards the olivary body: near their origin the network in the antero-lateral column, through which they pass, is crowded with cells, of all shapes and sizes, which send out their processes in every direction between the longitudinal fasciculi, and probably establish a most intimate union of the parts amongst which they lie. Some of the fibres of these bundles, as well as separate fibres issuing from the white column, may be traced into this nucleus; but others turn inwards, and after running along the border of the white column and lower part of the nucleus, they decussate through the raphè with their opposite fellows. Along each side of the raphè runs a considerable blood-vessel, which sends out lateral branches to follow the bundles of the plexus and anastomose with the vessels that accompany the antero-posterior bundles just described.

(57.) The *glossopharyngeal* nerve passes inwards and backwards, in two or three bundles, through the gelatinous substance and across the arciform fibres. On reaching the group of longitudinal fasciculi, which lie at the extremity of the vagal nucleus and now adjoin the network of the posterior pyramid, its outer portion separates, in a brush-like manner, into many smaller bundles, which subdivide the fasciculi into a corresponding number of parts, and interlace between and around them: many of its fibres at this point *appear* to become longitudinal; some turn into the auditory ganglion, along the lateral border of which they may be traced in part through the network of the posterior pyramid (*b*); the middle fibres of the nerve proceed to the remaining cells of the vagal nucleus, and many of them appear to extend as far as the group of cells that form the commencement of the *fasciculus teres* and the continuation of the hypoglossal nucleus: as in the case of the vagus, the anterior portion of the nerve, forming a distinct bundle, turns inwards round the summit of the antero-lateral column, and passing through the most anterior and largest cells, sends forward a series of returning loops, first through the antero-posterior bundles along the inner border of the *caput cornûs posterioris*, and then in succession through the network of the lateral column, as it makes its way towards the raphè (see fig. 36, Plate XVII.); but in this course its fibres lie side by side with those which have been already described as proceeding from the antero-lateral column in the same direction to decussate through the raphè with their opposite fellows, so that it becomes almost impossible to identify them and ascertain if they share in the decussation; that they do so, however, is rendered extremely probable by the fact that in Birds *all* the fibres of the eighth pair of nerves, of which the highest correspond to the *glossopharyngeal*, may be distinctly seen to decussate through the

raphè after passing through and around their nuclei. I have by me many preparations showing this course in the most satisfactory manner.

(58.) It has been shown that the grey substance behind the central canal, after forming the cells in the *post-pyramidal* ganglion, becomes itself the *nucleus of the eighth pair of nerves*, and increases by encroaching on the pyramid, to the remains of which it appears again to contribute for the formation of the *auditory ganglion*: there would seem, therefore, to be, if I may use the expression, a kind of family relationship between these two vesicular centres; and, moreover, the under or anterior division of the auditory nerve, which takes its origin from the network of the posterior pyramid behind the caput cornûs posterioris, adjoins the upper fibres of the glossopharyngeal, as the latter do those of the vagus.

Explanation of the Plates.

PLATE XII.

Fig. 1. Under surface of the brain of the Cod-fish:—A, olfactory nerves, attached to a delicate membrane; B, optic nerve, drawn aside; C, cerebral hemisphere, slightly wrinkled or folded; D, optic lobe; E, anterior column.

Fig. 2. Under surface of the brain of the domestic Fowl.

Fig. 3. Under surface of part of the brain of a young Dog:—F, crus cerebri; G, pons Varolii; H, part of the lateral lobe of the cerebellum; *s*, trapezium; g', vesicular column on the outer side of the olive.

Fig. 4. Under surface of a portion of the brain of a Cat:—C′, C′, middle and posterior lobes of the cerebrum.

Fig. 5. Posterior surface of the human *medulla oblongata*:—*a*, restiform body; *b*, *b*, posterior pyramids; *d*, *portio mollis* of the seventh nerve; *r*, *r*, vesicular columns or nuclei of the *hypoglossal* nerves, continuous with the *fasciculi teretes*; *t*, *t*, pyriform nuclei of the *vagus* nerves.

Fig. 6. Side view of the human *medulla oblongata*, enlarged:—*i*, anterior pyramid; *h*, olivary column; *g*, lateral column; *f*, *tuberculo cinereo*, or expanded extremity of the posterior cornu; *a*, restiform body; *b*, posterior pyramids.

Figs. 7, 8. Side views of the *medulla oblongata* of the Sheep:—*s*, trapezium; s', *portio dura* of the seventh nerve; s'', fifth nerve.

Fig. 9. Under surface of the *medulla oblongata* of the *Cheetah*, or hunting *Leopard*. The largely-developed *arciform* fibres are represented on the right side.

Fig. 10. Transverse section at the commencement of the human *medulla oblongata*:—*f*, caput cornûs, or expanded extremity of the posterior cornu; f'', posterior roots of the first cervical nerve; g'', spinal-accessory nerve; I, anterior columns.

Fig. 13. Transverse section of the *medulla oblongata* of the Sheep, at the lowest roots of the hypoglossal nerves *z, z*:—g'', spinal-accessory nerve proceeding through the network into which the lateral grey substance is resolved.

Fig. 14. Similar section through the lower part of the protuberance i' (fig. 8):—*i, i*, anterior pyramids enclosing the olivary bodies.

PLATE XIII.

Fig. 11. Transverse section of the human *medulla oblongata* at the point of the anterior pyramids, showing the commencement of the decussation:—*i, i*, anterior columns. The anterior cornua are pierced by numerous longitudinal bundles, amongst which the nerve-cells are scattered. A network of fibres from the lateral grey substance proceeds outwards between bundles of the lateral column: f''', fibres of the posterior roots running backwards through the posterior column.

Fig. 12. Oblique section from before backwards, through the lower part of the anterior pyramids, in the plane of the decussating fibres which proceed from the lateral columns:—*a*, commencement of the restiform ganglion; *b*, commencement of the post-pyramidal ganglion; *i, i*, anterior pyramids.

Fig. 15. Transverse section of the *medulla oblongata* of the Cat, through the broadest part of the decussation:—*f, f*, grey tubercles of Rolando.

Fig. 16. A similar section from the *medulla oblongata* of the Dog:—*b*, posterior pyramids.

Fig. 17. Similar section from the Guinea Pig.

Fig. 18. Transverse section of the *medulla oblongata* of the domestic Fowl:—g'', spinal-accessory nerve.

Fig. 20. Cells from the human *post-pyramidal ganglion*; magnified 420 diameters.

Fig. 21. Cells from the human *restiform ganglion*; magnified 420 diameters.

Fig. 22. Cells from the human *olivary body*; magnified 420 diameters.

PLATE XIV.

Fig. 23. A transverse section of the human *medulla oblongata*, immediately below the olivary bodies:—*a, a*, restiform bodies containing the restiform ganglia, or grey substance developed from the back of the *cervix cornûs posterioris*; *b, b*, posterior pyramids, containing the post-pyramidal ganglia; *f*, the grey tubercle of Rolando, or expanded extremity of the posterior cornu—the *caput cornûs*. At its root, *d*, fibres proceeding from the central part of the posterior grey substance are mixed in an intricate plexus, which encloses in its meshes numerous longitudinal bundles (represented by the dark spots), and contains a number of cells of different shapes (but represented by the small circles),

which send out their processes both transversely and longitudinally; *c*, are fibres radiating from the restiform ganglion, and from the decussation of the anterior pyramid of the opposite side, into the white substance of the restiform body; *g'*, a vesicular tract imbedded in the lateral column on the outer side of the olivary body. The group of small cells, resting on the back of the anterior pyramid, *i*, form the commencement of the olivary body; I, I, the non-decussating portions of the anterior pyramids; their posterior halves are divided into numerous bundles by the decussating fibres; *p*, a group of large stellate, oval, fusiform, pyriform and crescentic cells imbedded in the lateral column amongst the network represented on the opposite side of the figure: the whole of this network, enclosing longitudinal bundles, is interspersed with cells of different shapes and sizes, which frequently embrace the bundles, and send their processes longitudinally and transversely in different directions. Behind and on each side of the central canal is the commencement of the nucleus of the spinal-accessory nerve; and in front of it, on each side, is that of the hypoglossal nerve: *x* is the commencement of the superficial arciform fibres.

PLATE XV.

Fig. 24. Longitudinal section of the human olivary body, with part of the olivary column, showing the convolutions of the grey lamina, or *corpus dentatum*.

Fig. 25. A series of convolutions of the grey lamina of the human olivary body; on the left side the cells of the lamina are represented:—O, O, part of the central white nucleus; Q, Q', Q, part of the antero-lateral column.

Fig. 26. Anterior pyramids, *i*, *i*, and olivary bodies, *k*, *k*, of the Sheep: on the left side the arciform fibres are seen winding through them.

Fig. 27. Anterior pyramids and olivary bodies of the Cat: the olivary commissure, joined by the arciform fibres, is seen decussating across the raphè.

PLATE XVI.

Fig. 28. Transverse section of the human *medulla oblongata* through the lower part of the olivary bodies:—r, *spinal-accessory nucleus*; g'', *spinal-accessory nerve*; t, *hypoglossal nucleus*.

Figs. 29, 30, 31, 32. A series of similar sections from the point of the *calamus scriptorius* to the upper roots of the *vagus* nerves (*f'*):—*x*, superficial arciform fibres.

Fig. 33. Transverse section of the *medulla oblongata* of the Sheep, immediately below the point of the *calamus scriptorius*:—*r*, *r*, vagal nuclei joined by their transverse commissure, which forms the roof of the upper extremity of the canal.

PLATE XVII.

Fig. 34. Part of the *raphè* of the human *medulla oblongata*. It is traversed from before backwards by numerous straight fibres, some of which are continuous with fusiform cells:—*a'*, *a'* are bundles from the deep arciform plexus on each side, interspersed with cells of different shapes, and decussating through the *raphè*. Some of the fibres at the edge of the raphè form loops between the bundles; *b*, *b* are longitudinal fasciculi of the antero-lateral columns.

Fig. 35. Transverse section of the hypoglossal nucleus, *t*, and of part of the spinal-accessory nucleus, *r*, of the Sheep; *z*, hypoglossal nerve; *g''*, spinal-accessory nerve; C, central canal; R, the raphè.

Fig. 37. Cells of the human vagus ganglion magnified 420 diameters; some of them are pigmentary.

For explanation of fig. 36, see § 56, page 254, text.

Figs. 38, 39, 40. Left halves of the *medulla oblongata* of *Cercopithecus*, *Semnopithecus*, and the *Wanderoo* Monkey:—a, *anterior pyramid*; b, *olivary body*; c, *trapezium*.

Fig. 41. Left half of the *medulla oblongata* of *Ursus Syriacus*:—*d*, arciform fibres.

XV. *On the* Megatherium (Megatherium Americanum, Cuvier *and* Blumenbach). Part IV.—*Bones of the Anterior Extremities.* *By Professor* Owen, *V.P.R.S., Superintendent of the Natural History Departments in the British Museum.*

Received May 6, 1851,—Read May 8, 1851.

The bones of the limbs of the Megatherium are not less fraught with interest to the Comparative Anatomist and Physiologist, than are those of the trunk and head, by reason of their peculiar proportions and configurations, and more especially as the unguiculate type on which they are constructed is exemplified in a quadruped of such enormous bulk. The anterior extremities (Plate XVIII.) exceed the posterior ones in length: in their bony structure they include a complete clavicle (52) with the scapula (51), a humerus (53), an antibrachium, consisting of fully developed and reciprocally rotating radius (55) and ulna (54), carpus, metacarpus, and four digits; they manifest, in short, all the main perfections of brachial structure, save the opposable thumb, observable in the mammalian class. These perfections, moreover, are associated with proportions and processes indicative of enormous strength, and bespeak a limb fitted not only to take its full share in the support of the body, but to be employed on operations in which unusual resistance had manifestly to be overcome. In no respect, perhaps, does the Megatherium more strikingly differ in its osseous structure from the existing quadrupeds of corresponding bulk, than in the bony fulcra of the anterior extremity.

Scapula.—The scapula (Plate XVIII. 51, and Plate XIX. figs. 1 and 2) is a vast expanse of bone, with a double spinous process; the normal one expanding into a large acromion, which is continued into, and is confluent with, the coracoid process. The scapula usually presents an inequilateral triangular form (Plate XIX. fig. 1), of which the acromion (*k*) is the apex. The upper border (*b*, *c*) is the shortest; but, in one specimen, owing to the greater development of the basal border, as indicated by the dotted outline in Plate XIX., the upper border appeared to begin at the part of the base marked *a*, and to form a low angle, as if continued about one-fourth of the distance from the base parallel with the lower border, whilst the rest of the costa inclines downward towards the coracoid (*c*), with a slight concave outline. The upper border increases in thickness as it passes into the origin of the coracoid. The base of the scapula, from the point *a*, is straight as far as the origin of the spine, *a'*; it then bends, with a convex curve, and increases in thickness to the inferior angle of the scapula (*d*), close to which commences the second or lower spine. The inferior costa of the scapula extends forward, straight and parallel with the lower spine, for some way, and then is lost upon the inner

surface, the lower spine itself appearing, at *e*, to form the inferior costa for the rest of its course to the glenoid cavity (*g*).

The normal spine of the scapula, notwithstanding its being the superior of the two, commences at only one-fourth of the entire base of the bone from the inferior angle; it is thence continued forwards, gradually rising or gaining depth, parallel with the inferior costa, and thus marks out a very large proportional extent of the outer surface of the bone for the supraspinal fossa (Plate XVIII. [a]). As the spine advances, it increases in breadth as well as depth, until it springs clear of the main body of the bone as the acromial process, *k*. This large, thick and rough process (Plate XIX. fig. 2, *k*) arches forward and upward over the glenoid articular cavity (*g*), and meets and coalesces with the coracoid (*c*), spanning the anterior outlet (*f*) of the supraspinal fossa by a strong and broad bridge of bone. Through the reciprocal modification of the coracoid, the passage for certain vessels and nerves, which is usually in Mammals a mere notch of the upper border of the scapula, is converted into a complete foramen (Plate XIX. fig. 1, *h*). The second spine, which answers to the ridge defining the upper part of the fossa for the 'teres major' muscle in Man, runs parallel with the upper spine, and then bends down to terminate in the low angle (*ib.* fig. 1, *e*), projecting from the inferior costa of the scapula, about one-third of the length of that border from the glenoid cavity (*g*). The shape of that cavity is almost an ellipse (Plate XIX. fig. 2, *g*), the lower end being scarcely more contracted than the upper one: both these parts of the periphery are rather more produced than the lateral borders. The entire margin of this moderately deep and well-defined articular cavity is thin, but convex. The inner surface of the scapula (Plate XIX. fig. 1) is divided into many shallow depressions by intermuscular ridges (*i*, *i*), having a general tendency to converge from the basal border, where most begin, towards the centre of the bone, though none extend so far. The inferior costa (*d*) is continued more directly towards the inner side of the glenoid cavity by a smooth, convex rising of the inner surface, which grows broader as it gradually subsides: the fore-part of the lower costa (fig. 1, *e*) is rather a continuation of the inferior spine; between which and the portion of the lower costa (*d*), is the wide channel, attesting the size and force of the homologue of the *teres major*. The vigour of the enormous *subscapularis* muscle is manifested by the intermuscular ridges (*i*, *i*).

Compared with the scapula of the Mylodon, that of the Megatherium differs in the lower position of the spine, and the consequent greater expanse of the supraspinal fossa: the base is straighter and relatively longer, the inferior costa relatively shorter. The ridge extending from the inferior and posterior angle forwards upon the under surface of the scapula, is relatively stronger in the Megatherium, and gives to the homologue of the inferior costa in the Sloth's blade-bone the character of a second spine. As such 'second spine,' with a prolongation of the scapula below, characterizes that bone in the Anteaters, this indication of affinity to *Myrmecophaga*, or rather manifestation of the more general characters of the order *Bruta*, by the Megatherium, is not without interest.

The confluence of the acromion with the coracoid is peculiar to the Sloths amongst existing Mammals.

Clavicle.—Before the discovery of the Megatherium, Man was usually cited in Manuals of Comparative Anatomy as the largest animal possessing a 'collar-bone': he is, in fact, the largest existing animal so endowed. But whilst the length of the human clavicle averages but 6 inches, that of the Megatherium is 15 inches. In its general shape and sigmoid curve, this bone (Plate XX. fig. 1) singularly resembles the human clavicle, but is thicker in proportion to its length. No single bone would have better excused the common conclusion of the mediæval anatomists as to the nature of large fossil bones, viz. that they were those of human giants, than the collar-bone of the Megatherium.

The sternal end is expanded, obliquely truncate, with a rough, irregular, undulating, but mainly convex articular surface, much fitted for strong ligamentous attachment to the manubrium sterni, and with a narrow, rather flattened facet above this surface, where it abuts against the same part in its fellow, as shown at Plate XVIII. *ss*.

The shaft of the bone is most contracted at its sternal third part; thence it gradually expands to the acromial end; the anterior surface is moderately smooth and convex: the posterior surface (Plate XX. fig. 1) is rough and more flattened, and is traversed obliquely by a broad ridge, which terminates outwardly, or developes the rugged upper border of the acromial half of the bone. This expanded end bends downward, as the sternal end bends upward. There is a large tuberosity on the outer or fore-part of the acromial expansion, which terminates in an oblong convexity, adapted to the concavity beneath the expanded end of the acromion. The strong aponeurotic character of the periosteum of the clavicle is well shown by the linear decussating ridges on most parts of the surface of the shaft. The bone is solid.

The closer affinity of the *Bradypus didactylus*, as compared with the *Brad. tridactylus*, to the Megatherium, is illustrated by the complete clavicles which attach the scapulæ to the sternum; but they are straighter, relatively more slender, and more suddenly expanded at the sternal end than in the Megatherium. One species or variety of Three-toed Sloth has only a small styliform clavicular bone, appended to the coracoid process. The clavicle in *Orycteropus* and *Myrmecophaga* is complete, but has a single curvature. The clavicle of the Mylodon is intermediate, in its form and proportions, between that of the Megatherium and that of the Two-toed Sloth.

The supposed peculiarity in the articulation of the clavicle of the Megatherium with the first rib instead of the sternum, which Cuvier inferred from the figures and descriptions of the fossil animal which had been published in his time*, is shown by the more perfect specimens since received, not to exist in nature; and the suspicion expressed by the great anatomist, viz. that it might be due to some misarticulation in the Madrid skele-

* "D'après les figures et les descriptions, il paraîtrait que cette clavicule s'articulerait, non pas avec le sternum comme à l'ordinaire, mais avec le bas de la première côte qui est recourbée, et présente une concavité pour la recevoir. Ce serait une singularité dont je ne connais pas d'exemple."—Ossemens Fossiles, Ed. 1835, 8vo, tom. viii. p. 349.

ton, is thus proved to be well-founded. The true connexions of the sternal ends of the clavicles with each other and with the manubrium sterni, are well shown in the view of the skeleton in the British Museum, given in Plate XVIII.

Humerus.—The humerus (Plate XX. figs. 2—5) is remarkable for the vast expanse of the lower fourth part of the bone; but this is limited to the transverse direction; so that, viewed sideways (as in Plate XVII. Phil. Trans. 1855), the humerus of the Megatherium appears to be a comparatively weak and slender bone: the whole shaft, however, gives indications of the force of the thick muscular masses which surrounded and operated on it.

The head of the bone (Plate XX. fig. 4) presents a smooth convexity of an elliptical form, corresponding with that of the glenoid cavity of the scapula; the long axis of the ellipse is from before backward. The head rises clear above the outer and inner tuberosities, neither of which are so developed as to interfere, as in ungulate quadrupeds, with the free rotation of the bone.

The rugged surface of the inner tuberosity (*ib.* figs. 2 and 3, *a*) slopes downward and inward (ulnad) from the peripheral groove of the head, marking the attachment of the joint-capsule. The pectoral ridge is continued from the lower, slightly outstanding, part of this tuberosity. The outer tuberosity (ib. *b*) projects from a lower level, is larger and more prominent than the inner one; and is divided into two subequal rough facets. The outer deltoid ridge begins from the outer side of the tuberosity; the inner deltoid ridge (ib. *d*) some inches lower down, and nearer the inner side of the shaft: these ridges converge, strengthen as they descend, and coalesce at the beginning of the lower third of the shaft, defining a long and narrow angular tract for the implantation of the powerful deltoid muscle. A tuberosity (ib. *c*) is developed from the outer (radial) side of the humerus, one-third down the bone, from which a strong ridge descends along the same side of the middle third: this ridge is defined below, and divided from the supinator ridge, by a deep and smooth oblique channel (ib. *e*) for the passage of vessels and nerves from the back to the fore-part of the bone. The supinator ridge (ib. *f*) is the most prominent feature of the lower third of the humerus; it presents a long, triangular, rough outer facet, widening as it descends, and with a secondary ridge from its middle part. The longitudinal contour of this facet forms an obtuse angle with the lower half of the ridge, extending to the outer condyle of the humerus: the outer facet of this half is rough, triangular, with the base upward. The pectoral ridge (*ib.* fig. 3, *i*) terminates in a low tuberosity (ib. *h*) on the inner side of the middle of the shaft; whence a second ridge is continued upward upon the back of the shaft. This surface is flatter than the fore-part, especially at its lower expanded third; at the bottom of which, midway between the outer and inner supracondyloid productions, and just above the lower articular surface, is a small but well-defined olecranal depression. The inner supracondyloid angular production (ib. *k*) has the flat rough facet only upon its lower half. Owing to the production of these ridges, the articular condyles themselves (ib. *g*, *l*) appear to occupy but a small part of the distal end of the bone; for the extreme breadth of this end being

13 inches, that of the articular surface is but 7½ inches. It consists of two convexities, side by side, divided by a narrow and deep channel, continued from the front non-articular surface half-way towards the back part of the bone. Both convexities have a full elliptic periphery; the outer one (*ib.* figs. 2, 3, 5, *g*) with the long axis from before backward, the inner one (ib. *l*) with the long axis from side to side: the outer condyle is the larger and more prominent of the two; it forms more than a hemisphere, the antero-posterior contour describing full three-fourths of a circle. The extent of flexion and extension of the fore-arm on the arm is thus shown to be considerable. The articular surface continued from one condyle to the other is concave transversely.

The centre of the shaft of the humerus is occupied throughout by a coarse cancellous structure. A very small medullary artery penetrates the back part of the bone, below the pectoral tuberosity, the canal extending obliquely downward and outward.

The *Myrmecophaga didactyla*, amongst existing *Bruta*, most resembles the Megatherium in the development of the supinator or outer supracondyloid ridge.

In its general proportions the humerus of the Megatherium resembles that of the Megalonyx; and is more slender, in proportion to its length, than in the Mylodon or Scelidothere. The articular head forms a larger proportion of a sphere, and projects more freely beyond the tuberosities: these are relatively smaller, and are more equal than in the Mylodon or Scelidothere: the external tuberosity, in particular, is more developed in these smaller Megatherioids. In them also the external ridge is continued from above the 'musculo-spiral' groove inwards, along the front of the humerus to the apex of the deltoidal tract, forming its outer boundary: in the Megatherium, a smooth concave surface divides the outer ridge from the deltoidal elevation, which is absolutely narrower. The vertical outline of the back part of the shaft of the humerus in the Megatherium is almost straight, being but a little bent forwards at its lower third, as it is likewise in the Megalonyx; and, in both, the olecranal depression is well defined: in the Mylodon and Scelidotherium, the same outline of the humerus is slightly concave; the lower third of the bone being, as it were, a little bent back below the deltoidal platform; and the olecranal fossa is not defined. The inner supracondyloid plate is produced at its upper part into a strong tuberosity, in both the Mylodon and Scelidotherium, but not in the Megatherium.

In the existing Sloths, the humerus at this part, viz. above the inner condyle, is perforated in one genus (*Cholœpus*) and not in another (*Acheus*, F. Cuvier): and the same difference occurs in the great extinct Sloths. In the Megatherium the humerus is imperforate, as it is in the Mylodon: in the Megalonyx and Scelidotherium it is perforated above the inner condyle. Yet the Megalonyx most resembles the Megatherium, not only in the general proportions of the humerus, but in the configuration of its two articular ends. The inner or ulnar condyle, *e. g.*, is convex in every direction in the Megalonyx as in the Megatherium: in the Mylodon and Scelidotherium it is convex only from before backwards, but is concave from side to side. In the more robust proportions, in the shape of the articulations and the development of the processes of the

humerus, the Mylodon and Scelidotherium as closely resemble each other, as the Megatherium resembles the Megalonyx in the same characters; yet the humerus of the Scelidotherium has the inner perforation, and that of the Mylodon a groove merely, for the brachial artery and nerve. This variety, and the corresponding one above noticed between the Megatherium and Megalonyx, show the inapplicability of the final cause commonly assigned to the ento-condyloid hole, the existence or otherwise of which depends merely on the ossification or non-ossification of the aponeurosis extending from the shaft of the humerus to the ento-condyloid process.

Ulna.—The bones of the fore-arm in the Megatherium, as in the Megalonyx, exemplify by their greater length, as compared with those of the same segment in the hind limb, the Bradypodal affinities of these huge extinct quadrupeds.

The ulna in the Megatherium (Plate XXI. figs. 1, 2, 3) is, however, peculiar for the vast expanse of its proximal end, in connexion with its long and slender shaft. The olecranon (ib. *a*) is twice as broad as it is long; its inner border, springing from the notch which penetrates the inner and back part of the humeral articular fossa, extends obliquely upward and inward for 3½ inches, the ridge or edge of the plate being about an inch in thickness: the plate from this ridge sweeps round the back part of the bone, subsiding and increasing in breadth as it approaches the radial side, where it terminates in a tuberosity, divided by a groove from the radial articular cavity (ib. *b*), and prolonged downward into the ridge bounding the radial side of the upper half of the ulna. The olecranon projects rather backward than upward, and is strengthened and supported at its highest part by a strong angular buttress, which gradually subsides upon the back of the ulna.

The great 'sigmoid' articular surface is divided into two facets by a median portion, which is produced forward in the longitudinal or vertical direction, and is convex from side to side; the divisions so defined are concave. The inner one (ib. *c*), for the inner humeral condyle, describes a semicircle from behind forwards; it has little more than half that extent from side to side, and is encroached upon by a narrow, rather deep, rough channel, continued from the inner origin of the olecranon, expanding, to near the middle of the cavity. The outer division of the sigmoid fossa (ib. *b*) has reverse proportions, the transverse being nearly double the extent of the longitudinal diameter, and it is less concave than the inner division; about half an inch of its lower border bends a little back for the articular margin of the head of the radius, just above the rough fossa, for the reception of the non-articular part of the same head: the rest of the outer division of the sigmoid cavity receives the back part of the outer condyle of the humerus. Below the outer division the radial fossa (ib. *d*) presents a triangular form, bounded by a rough ridge externally and by a tuberosity internally. The ridge is continued upon the radial side of the shaft of the ulna to within a fourth part of its distal end; the surface of this side of the bone is irregularly sculptured, indicating the strong ligamentous connexion between the ulna and radius at this part. The back and inner sides of the shaft of the ulna are comparatively smooth.

A vascular canal, somewhat larger than the rest, is seen near the fore-part of the outer surface, entering the bone obliquely upward. A rising of the surface, with a linear series of three or four rough tubercles, marks the lower fourth of the inner side of the bone; a short wide longitudinal channel marks the back surface of the distal end (fig. 3), which is slightly expanded and convex, and so impressed as to indicate its ligamentous junction with the carpus.

The ulna of the Megatherium differs from that of the Mylodon, not only in its longer and more slender proportions, but also in the absolutely as well as relatively minor height or length of the olecranon; in the much less relative vertical or longitudinal extent of the outer division of the 'sigmoid' cavity; and in the 'haversian' fossa on the inner division. It differs in the much narrower channel dividing the articular cavity from that part of the base of the olecranon which is continued into the posterior ridge or border of the shaft; it differs, also, in the convexity of the distal end and the absence of the articular facet, which is distinctly present in that part of the ulna in the Mylodon and Scelidotherium.

Radius.—The radius (Plate XXI. figs., 4, 5, 6), like the ulna, of the Megatherium resembles in its longer and more slender proportions that bone in the Megalonyx, and differs from the proportionally thicker and shorter radius of both the Mylodon and Scelidotherium. The proximal end is circular, and is occupied by a smooth, moderately shallow, articular cavity (*ib.* fig. 5), with a well-defined border, over which the articular surface extends, on the ulnar side of the head, for about half an inch down; which tract is adapted to the lower portion of the outer division of the sigmoid cavity of the ulna. The articular modification of the head of the radius is as completely adapted for the superadded rotatory movements of the antibrachial bones, as in the human subject, to the head of the radius of which the resemblance of that of the Megatherium is strikingly close.

The shaft of the radius gradually narrows, in the antero-posterior diameter, along the upper fourth part, but maintains the same diameter as the head, transversely. Three inches below the head, on the inner and fore-part of the shaft, is the tuberosity (ib. *a*) for the tendon of the biceps, which measures 3 inches in long diameter and 1¾ inch across. Here the bone bends a little outward (radiad); and the ridge bounding that side is developed into what may be termed a process (ib. *b*), with a low angle, whence the ridge is continued straight down the lower half of the shaft to near the tuberosity above the styloid process (ib. *c*), where it curves outwardly to terminate in that tuberosity. The fore-part of the shaft is moderately smooth and convex across; it describes, lengthwise, a slight concavity; on the inner side of the bone, a broad and very rugged tract begins, about an inch and a half below the bicipital tuberosity, and extends along the middle third of the shaft; a less rough tract is continued thence, gradually expanding to the cavity for the lower end of the ulna. The outer side of the shaft of the radius is smooth, convex across, and with a slight convexity in its longitudinal contour: from the external process downward the radius maintains an equal breadth near the lower end, and

there it expands in all directions to form the large articular cavity (ib. *d* and fig. 6) for the major part of the carpus. Above this cavity, on the ulnar side, is the rough and shallow depression for the ligamentous junction of the corresponding end of the ulna; on the front side a broad low ridge extends obliquely from the suprastyloid tuberosity to the border of the cavity; on the back part three oblong, short, thick ridges or tubercles divide the surface into four channels, for tendons; three of these are longitudinal and parallel, progressively increasing in width from the innermost (or one next the ulna) to the third; the outermost passes obliquely between the suprastyloid tubercle and the styloid process. This process is short and thick, rounded at the end; flattened in front, with the smooth articular surface continued for a few lines upon the lower border of this surface, from the general articular cavity which is extended over the lower end of the radius including the styloid process. This cavity presents a triangular form with the angles rounded off; the base next the ulna is short and oblique; the anterior border or side is the longest, the opposite border is the thickest, and is notched near the styloid process: the cavity is moderately concave, and articulates with the scaphoid and lunar bones of the carpus.

In the Mylodon the radius is not only thicker in proportion to its length, but is more extensively and deeply impressed by the muscles of the fore-arm, especially on the back part of the bone. The tuberosity for the insertion of the biceps is further from the proximal joint, and augments the power of the muscle in the same degree: the proximal articular cavity is of an oval form.

Carpus.—The carpus (Plate XXII. *s*....*u*) consists of seven bones, four in the proximal and three in the distal row.

Scapho-trapezium.—The first of the proximal row (ib. *s*) includes the bone (ib. *t*) answering to the first of the distal row in Man and most Mammals, and is consequently a 'scapho-trapezium' (*s*, *t*)*, as it is also in the Sloths, the Mylodon and Scelidotherium. It is of an irregular triangular shape, with its base applied to the 'lunare' (ib. *l*), and with the apex somewhat twisted. It presents a broad convex articular surface (*ib. s*) for the outer half of the concavity of the radius; and this surface is continuous with a crescentic one of about one inch in breadth, which covers the proximal part of the side of the bone next the os lunare. The palmar or anterior horn of the crescent is continuous with an oval flat articular surface joining the os magnum (ib. *g*): the opposite or dorsal horn is separated by a rough tract from a convex subquadrate surface which also articulates with the os magnum. On the outer side of this surface, and, like it, on the fore-part of the bone, is a surface concave in one direction and convex in the opposite direction, for articulation with the small trapezoides (ib. *z*). External to this, the fore-part of the produced and twisted apex of the bone, which represents the trapezium, articulates with the stunted metacarpal of the pollex (ib. *m* I), chiefly by

* This is the bone called 'cuneiforme' in CUVIER's chapter on the Megatherium, and which is marked *r* in the copy of Dr. PANDER's figure of the Madrid skeleton introduced into plate 217, fig. 3, of the edition of the 'Ossemens Fossiles,' 8vo, 1835, here cited.

ligament, but also by a small elliptical flat surface which seems to have been covered with articular cartilage. Between the two facets for the os magnum the bone is deeply excavated and has been perforated by blood-vessels.

Lunare.—The 'os lunare' (Plate XXII. *l*) offers, as in Man, some rude resemblance to a crescent; its proximal surface, very convex from before backward and rather convex from side to side, is wholly covered by the smooth articular surface which plays upon the ulnar half of the terminal cavity of the radius; and this surface is continued upon the radial side of the bone to form there the crescentic tract, adapted to the similarly-shaped tract on the scaphoid. The inner horn of this tract is continuous with the surface, convex at the fore-part, then deeply concave from before backwards, for the os magnum (ib. *g*): this articular surface is continuous with a similarly deeply excavated and irregular one on the ulnar half of the fore-part of the bone, which is subdivided into three facets, the middle one for the os cuneiforme, the two smaller ones for two parts of the os unciforme.

Cuneiforme.—The 'os cuneiforme' (ib. *c*), which is the smallest of the three proximal carpals, presents at its radial side a triangular convex surface for articulation with the lunare; and at its fore-part an irregular concavo-convex oblong surface for the unciforme (ib. *u*). Its proximal surface is tuberous and rough for ligamentous attachment to the ulna, except where the smooth articular surface for the os pisiforme is situated: this surface is in great part convex.

In the Mylodon the os cuneiforme is the largest of the carpal bones.

Pisiforme.—The os pisiforme (Plate XXII. *p*) is conical with an obtuse apex, having on its base the articular surface for the os cuneiforme, and with the rest of its exterior surface more or less irregular, for implantation of a tendon and ligaments.

Trapezoides.—The homologue of the trapezium being connate with the scaphoid, and noticed in the description of that compound bone, the trapezoides (ib. *z*) is the first independent carpal bone of the distal row. It is the least of the carpal series, and is a relatively smaller and flatter bone than in the Mylodon: the proximal or scaphoidal surface is convex transversely, concave from behind forward, and plays in a corresponding concavo-convex surface in the scaphoid. The distal surface is almost wholly convex: both surfaces are joined by a small articular facet on the radial side of the bone, which is adapted to a corresponding facet in the small metacarpal bone of the thumb; and by a more extended articular surface on the ulnar side of the bone for junction with the os magnum.

Magnum.—This bone, arbitrarily so termed, comes next after the trapezoides and pisiforme, in the order of size, being much inferior to the other carpals. It is almost wholly covered by smooth articular surfaces. The small non-articular rough surface (ib. *g*) exposed upon the back of the wrist is of a transversely extended hexagonal figure, with the outer and inner sides the shortest. The surface for the lunare is concave anteriorly, but very convex in the greater part of its extent. It is continuous at its radial border, with the two surfaces, one concave, the other flat, for the scaphoides; and at its ulnar

border with the flat surface for the unciforme. The concave scaphoidal surface is continuous with the surface for the trapezoides, which is much narrower than is the same surface in the Mylodon, the scaphoidal surface being broader than in the Mylodon. The largest articular surface is that for the base of the great middle metacarpal, which is slightly convex except at its fore-part, which is produced into a cone.

Unciforme.—Of all the carpals the os unciforme (ib. *u*) differs most in form from that of the Mylodon; it is a thick transversely extended bone, the free tuberous surface on the back of the wrist being hexagonal, with the two inner and the two outer sides very short; one of the outer sides is formed by a protuberance separating the articular surfaces for the os cuneiforme and fifth metacarpal, which meet at an acute angle in the Mylodon.

The proximal oblong concavo-convex surface for the cuneiforme is continuous, at the radial side of the bone, with the surfaces for the lunare and os magnum; and the latter with the broad surface along the distal part of the base which is obscurely divided into three facets, the middle and largest for the base of the fourth metacarpal, the next in size for the outer facet or the base of the third metacarpal, and the outermost and smallest facet for the small part of the base of the fifth metacarpal which articulates with the carpus. The inner or palmar rough surface of the unciforme has an oblong tuberosity, which is narrower than that upon the dorsal surface.

Metacarpus.—The innermost or first metacarpal (Plate XXII., I, *m*), answering to that of the pollex or thumb, resolves, by its rough obtuse distal termination, as well as by its diminutive size, one of the points considered doubtful by CUVIER, in the structure of the fore-foot of the Megatherium, by proving that the pollex was absent, or represented solely by the rudimental metacarpal, which must have been concealed beneath the integument. The bone is of an irregular subcubical shape, broader than it is long. At its base are two separate subcircular flat surfaces articulating with corresponding facets on the trapezial part of the scapho-trapezium: on the side next the second metacarpal is a convex articular surface, having the lower part obscurely defined for articulation with the trapezoides, and the rest lodged in the concavity, partly articular, partly rough, upon the outside of the base of the second metacarpal. The outer side of the rudimental first metacarpal is obliquely flattened, the surface here being apparently for the insertion of a strong tendon.

The metacarpal of the second digit (ib. *m* II*) has a very irregular exterior; its comparatively small base is excavated obliquely to receive the fore-part of the trapezoides; on the outer or radial side it shows a triangular excavation, the lower half of which has a smooth articular surface for the rudimental metacarpal, *m* I. On the ulnar side of the base there is a convex articular surface divided into a proximal narrow tract for the os magnum, and a distal broader tract for the contiguous side of the base of the middle metacarpal. Above or beyond this the middle third of the bone supports a rugged protuberance, which has been attached by ligament to a similar rough surface on

* Referred to the 'annulaire' or fourth digit in the 'Ossemens Fossiles,' *ed. cit.* pl. 216, fig. 8.

the middle metacarpal; so that little more than one-third of the bone projects freely from the metacarpus. This free part is subcompressed and expands in the direction from the back to the palm of the hand, so as to form the surface for a trochlear articulation of great extent in that sense. A ridge from the back surface of the metacarpal expands into a tuberosity near the dorsal end of that articulation; and a similar but smaller tuberosity projects from the palmar end of the same articulation, along each side of which there runs a thickish edge. The distal surface itself presents a median vertical or longitudinal prominence, beyond the lower half of which the articular surface is produced laterally so as to make the surface concave transversely on each side the median ridge; whilst at the upper half the whole surface is convex transversely, as it is, in a minor degree, longitudinally.

The middle metacarpal (ib. *m* III) is a little longer than the second, but is twice as thick, with a quadrate transverse section, the four sides of the shaft being flat and sharply defined. The base of the bone is produced 'ulnad' and 'proximad,' so as to be wedged between the fourth metacarpal, the magnum and the unciforme. The articular surface on the ulnar side of this production for the fourth metacarpal is extensive, and for the most part slightly convex; the surface on what may be termed the truncate end of the production, for articulation with the unciforme, is slightly convex on the dorsal half, slightly concave on the palmar half. The surface for the magnum on the proper base of the metacarpal sinks into a conical cavity near its dorsal end; the rest being nearly flat. On the radial side of the base is an oblong articular tract for the second metacarpal, and beyond this the extensive rough surface for the ligamentous connexion with the same bone. The radial surface is grooved above the rough facet, obliquely by a wide and moderately deep canal; apparently for the passage of a tendon to the digit. The dorsal surface shows an oblique broad tuberosity, extending from above the tendinal groove to the upper or dorsal end of the distal articulation. The smooth and almost flat dorsal surface gradually deepens into a broad and shallow oblique channel on the ulnar side of the oblique tuberosity. The ulnar side of the bone, beyond the articular surface for the fourth metacarpal, is occupied by a rugged flat tract for ligamentous connexion with the same bone. The palmar surface is pretty smooth, flat transversely, slightly concave lengthwise; produced into a tubercle below the middle prominence of the distal joint. The articular surface of this joint does not cover the whole distal end of the bone; it is long and rather narrow, extending obliquely from the palmar forward to the dorsal surface; the dorsal side of the bone being longer than the palmar one. It is traversed lengthwise by a median prominence, convex transversely, almost straight lengthwise; and the surface is continued upon a flat tract on each side of the prominence, that on the radial side of the prominence being the broadest.

The general form of this bone is more like that of a brick or of an ashlar stone for a strong wall, than like that of the usual support of a flexible digit of a fore-paw or hand.

The chief difference between the middle metacarpals of the Megatherium and Mylodon is in the form of the distal articulation. This surface, in the smaller Megatherioid,

is convex from above downward, whilst in the Megatherium it is straight, or rather concave, and it joins the dorsal surface at an acute angle. The lateral depressions of the pulley are narrower in the Megatherium, and the vertical inflexions of the phalanx must have been more limited than in the Mylodon.

The fourth metacarpal (ib. *m* IV), as compared with the third, is longer and more slender in the Megatherium than in the Mylodon; but its articulation by an obliquely extended base with the third and fifth metacarpals and the unciform bone, closely corresponds with that in the Mylodon*.

The two oblique metacarpal surfaces are nearly parallel, the radial one is concave, the ulnar one slightly convex; both are separated by a sharp angle from the intermediate or carpal surface, which is nearly square and is slightly concave. The proximal half of the bone is bounded by four flat equal sides, with intervening angles, sharp on the radial side. The upper and under sides are nearly smooth, with a broad low tuberosity near the proximal end; the outer and inner sides are rugged for close syndesmosis with the adjoining metacarpals. Only the distal half of the bone stands freely out; it expands in vertical breadth to the articular surface for the fourth finger. The angle between the upper and radial sides is rounded off; that between the upper and ulnar sides is, in one specimen, developed into a sharp ridge.

The distal articular surface resembles that of the second metacarpal, but occupies a smaller relative proportion of the whole distal surface; the vertical prominence, convex transversely, is broader, more concave vertically, and extends obliquely from the upper and radial angle to the lower and ulnar one: the flat lateral extension of the articular surface is confined to the radial side of the prominence. A single flat surface for a sesamoid bone is situated below, but distinct from, this part of the articulation. A large and strong tuberosity projects below the prominent part of the joint; an oblique channel divides this tuberosity from a longer one on the ulnar side of the distal end of the metacarpal.

The distal articular surface of the fourth metacarpal in the Mylodon is reduced to a small, vertical, oblong, nearly flat surface; this difference relating to the stunted development and limited function of the digit it has to support. In the Megatherium such simplification of the distal joint of the metacarpal is limited to the fifth of that series of bones (ib. *m* V): this metacarpal †, of the same length as the fourth, is more slender; its proximal end is wedge-shaped, the radial articular surface and the flattened outer facet converging to the narrow rough tract which is joined by ligament to the carpus. The articular surface on the radial side has a small terminal part obscurely marked off for a facet on the unciforme; the rest receives the convexity on the ulnar side of the fourth metacarpal: beyond this is a rough surface for the syndesmotic union of the contiguous bones. Rather more than half the fifth metacarpal stands freely out; it is traversed above by a longitudinal ridge expanding into a broad tuberosity at the distal end; the

* *Op. cit.* p. 92. pl. XV. *m* 4.

† Referred to the index or second digit in the 'Ossemens Fossiles,' *ed. cit.* pl. 16. fig. 11.

bone is smooth and rounded on the palmar side. The small terminal articular surface is oval, slightly concave vertically, concave transversely, upon the radial half of the distal expansion. There is no articular surface for a sesamoid.

The metacarpals are so united and wedged together and with the carpus, as to transmit from the oblique carpal surface which sustains the radius the weight of the fore part of the Megatherium to the fifth digit, the stunted extremity of which was imbedded in the marginal hoof-like callosity on which the ponderous quadruped trod, with the claw-bearing toes bent inwards.

From the scapho-trapezium and lunare the weight was transmitted to the second row of carpal bones; and by the oblique production of the base of the second metacarpal, and especially of the third metacarpal, it was concentrated through the medium of the fourth metacarpal upon the fifth. The lateral pressure thus occasioned explains the extent of syndesmotic and sutural union along the basal part of the metacarpals, and also the squared angular shape of the constituents of this masonry of the huge fore-paw.

On comparing the structure of the carpus in the Megatherium with that in existing Mammals, it is found to be repeated in the Unau or Two-toed Sloth (*Bradypus* (*Cholœpus*) *didactylus*), and in that species or subgenus exclusively; the carpal bones being seven, and the reduction to that number resulting, also, from the connation of the scaphoid and trapezium. A scapho-trapezial bone exists in the Ai or Three-toed Sloth (*Bradypus* (*Acheus*) *tridactylus*), but the carpus is further reduced in this species or subgenus to six bones by the confluence of the trapezoides with the os magnum. The trapezius is a distinct ossicle in the Chlamyphorus, as in most other Armadillos; in the *Dasypus sex-cinctus* it coalesces with the trapezoides. In the Pangolins (*Manis*) the scaphoid coalesces with the lunare, not with the trapezium. In the true Anteaters (*Myrmecophaga*), and in Orycteropus, the ordinary eight carpal bones retain their individuality.

Digital Phalanges.—The stunted metacarpal of the pollex, in the Megatherium, bore no rudiment of a digit. They were powerfully developed and unguiculate in the three following digits.

The index digit (Plate XXII., II) has three phalanges: the proximal one (1) is almost twice as broad, and more than twice as deep as it is long; the metacarpal surface presents a deep and wide, vertically elongated, subangular concavity, fitting the vertical prominence and lateral facets of the distal joint of the metacarpal; the distal surface of the proximal phalanx presents a vertical angular fissure dividing two oblong convexities. The mid-phalanx (*ib.* II, 2) has a proximal trochlea playing on the preceding, the median vertical ridge being overhung by the produced upper rough surface; the distal articulation repeats that of the proximal phalanx, but the median fissure is less deep, and the lateral convexities are more regularly rounded and prominent. The ungual phalanx (*ib.* II, 3) exceeds the length of both preceding phalanges; the upper or dorsal side of its base is produced backwards into an obtuse point; the rough sheath of the claw extends along three-fourths of the phalanx; it is convex radiad, vertical and flat ulnad;

the core presents a rough edge radiad and a vertical rough surface ulnad, and is smooth and convex transversely at its base, both above and below.

The proximal and middle phalanges of the digitus medius (*ib.* III, 1...3) are confluent, the line of anchylosis being indicated by a vertical ridge along both the inner and the outer sides, and by a curved ridge convex backwards on the upper or dorsal side. The proximal articular surface presents a deep vertical channel, with a narrow elongated subconcave surface continued from its radial side, and a still narrower flat surface from the opposite side. The distal articular surface of the composite bone has a deep median vertical groove dividing two convexities. The compound phalanx presents two rough tuberosities below, one terminating each bank of the vertical articular proximal channel; there is a smooth depression above, and another below, close to the distal trochlea. The enormous distal phalanx (ib. III, 3), of twice the vertical breadth of the adjoining claw phalanges, is very little longer than that of the second digit; it is flattest on the ulnar side, to which the upper convexity slightly inclines. The base or palmar part of the phalanx is the broadest, is convex both lengthwise and transversely, and is perforated by two canals, for the large vessels and nerves supplying the claw-core. The surface, in which was implanted the flexor tendon, shows many linear impressions radiating from the median tuberosity, forward and laterally. The articular surface excavates obliquely the base of this phalanx which overhangs the joint; the concave border of the median angular prominence describes a semicircle from above forward and downward; the ulnar excavation is longer in that direction than the radial one. The well-marked trochlear joint restricts the movements of the great claw to flexion and extension on a vertical plane, whilst its position effectually prevents retraction of the claw, the preservation of the effective condition of which is due to an opposite bend to that in the Cat-tribe, as was well explained by CUVIER in his description of the Megalonyx*. The major part of this enormous phalanx goes to form the sheath of bone protecting the base of the claw. The bony core or peg on which the claw was fixed and moulded is compressed, with a sharp edge above and flat below, where it projects beyond the sheath.

The finger of the fourth digit has three phalanges and is unguiculate, with a claw resembling in shape and size that of the second digit. The proximal phalanx (*ib.* IV, 1) is so compressed in the direction of its axis, that the proximal and distal articular surfaces almost meet above, only about 1½ line's breadth of rough surface there intervening: the proximal articular surface is a wide and moderately deep vertically-elongated channel, with a semielliptic flat surface continued from the lower half of the radial border; the outer and inner sides of the phalanx are narrow, elliptic rough convexities; the distal articular surface is gently convex vertically, sinuous laterally. The second phalanx (*ib.* IV, 2) is deeper than long; its upper surface is produced backward over the proximal phalanx into a rough obtuse process; the under surface is much shorter, but is broader than the upper surface; the convexity of the distal articular surface describes a semicircle from above downward, and is divided by a vertical trochlear groove into two parts,

* Ossemens Fossiles, *ed. cit.* t. viii. p. 510.

of which the ulnar one is the larger. The ungual phalanx (*ib.* IV, 3) is long, triedral, with the radial side of the sheath vertical, the under surface rough and flattened, and the ulnar surface sloping from above downward and outward to join the under surface. The upper posterior tuberosity, overhanging the joint, inclines radiad, and is somewhat flattened; the proximal surface presents a median vertical rising for the channel in the preceding joint.

The small elliptical surface on the radial half of the distal end of the fifth metacarpal supports a very short lamelliform phalanx, produced outward some way beyond the joint; and to this is articulated a stunted second phalanx with a rough, obtuse, non-articular end. In some instances the above two phalanges are blended together.

Amongst existing Mammals the Sloths alone present the connation of the scaphoid with the trapezium, the Two-toed Anteater and the Armadillo that of the first with the second phalanx. This latter character, peculiar to the middle digit in the Megatherium, is limited also to the same digit in the *Myrmecophaga didactyla*; in *Dasypus* it affects the third, fourth and fifth digits.

The *Bradypus tridactylus* has but two flexible phalanges in each of the three unguiculate toes, but this reduction is due to the early anchylosis of the proximal phalanx with the metacarpal, not, as in Megatherium, with the second phalanx. In the *Bradypus didactylus* the unguiculate digits preserve the normal number of free phalanges.

The pollex is atrophied in the Megatherium, as it is in both existing species of Sloth; and, as in the *Bradypus tridactylus*, only the second, third and fourth digits support claws; but the fifth digit, instead of being wanting, as in the Ai, is developed, so far as was needed for the purposes of terrestrial progression, in the Megatherium. The small existing arboreal Sloths are seldom obliged to walk on the ground, and there can only crawl along with difficulty. In the Mylodon the pollex was developed and unguiculate, but both the fourth and fifth digits were terminated by a stunted second phalanx. In the Unau, not only the fourth and fifth digits, but also the first are suppressed in the fore-foot. Yet this is the Sloth, as already remarked, which so peculiarly illustrates the bradypodal affinities of the Megatherium in the structure of the carpus, notwithstanding the degree to which the adaptive modifications of the Megatherioid type of fore-foot are carried in relation to the exclusively arboreal life of this small existing tardigrade. The coalescence of the scaphoid and trapezium, which CUVIER was the first to recognize in the existing Sloths, he continued to affirm in the latest edition of the 'Ossemens Fossiles' to be peculiar to them. The bony structure of the fore-foot of the Megatherium he regarded as most resembling that of the *Dasypus gigas*. M. LAURILLARD, after the subsequent reception of casts of the carpal bones of the Megatherium, which had been transmitted to England, with other bones of the Megatherium, by Sir WOODBINE PARISH, K.H., inferred that the fore-foot of the Megatherium had a greater analogy with that of the *Myrmecophaga jubata*, but he did not detect the connation of the scaphoid with the trapezium. The form of the scapho-trapezial bone in both existing Sloths bears an unmistakeable resemblance to that in the Megatherium, but in the Unau it

describes a deeper curve towards the palmar aspect, and the trapezial portion (described by DE BLAINVILLE as the sesamoid of the pollex*) is relatively longer than in the Megatherium. The base of the stunted metacarpal of the pollex is expanded, and abuts by one part against the trapezium and by another against the base of the second metacarpal. The trapezoides is a small bone articulated, as in the Megatherium, with the scapho-trapezial, the os magnum, and the second metacarpal; the os magnum presents almost the same pentagonal contour, dorsally, as in the Megatherium, the anterior facet being also partly convex for adaptation to a concavity in the base of the middle metacarpal, which likewise is so extended as to interpose itself between the fourth metacarpal and the carpus.

The atrophy of the fifth finger, which has proceeded in the Megatherium to cause the absence of the ungual phalanx, and which atrophy similarly affects both the fifth and fourth digits in the Mylodon and Scelidotherium, has proceeded in the Unau to the removal of all the bones of those digits, save the metacarpal of the fourth, which is reduced to a rudiment of even smaller size than that which forms the vestige of the thumb on the radial side of the hand: it rests, as a great part of the fourth metacarpal in the Megatherium does, upon the expanded base of the third metacarpal.

In the Ai (*Bradypus tridactylus*) the metacarpal rudiment of the pollex is anchylosed at its lateral joint to the base of the metacarpal of the index, but it retains its free articulation with the scapho-trapezium. The chief modifications of both hand and foot in the Three-toed Sloth are the extensive anchyloses of different bones: this character is shown by the coalescence of the trapezoides with the os magnum, such compound bone supporting the base of the second metacarpal and a great part of that of the middle metacarpal; thus fulfilling the same relations to the metacarpus as do the separated bones in the Unau and Megatherium.

The great extent to which the metacarpals are suturally united to each other in the Megatherium, is a character repeated in those of the Ai, but the suture is speedily, in the living Sloth, converted into bony union, and the three metacarpals, like the three metatarsals, thus form one compound bone, as in Birds. The unguiculate digits which this bone supports in the fore-paw, are the homologues of the three claw-bearing toes in the Megatherium. The rudiment of the fifth finger appears as a mere process from the outside of the base of the metacarpal of the fourth: the huge terrestrial predecessor of the small leaf-eating and tree-dwelling quadrupeds retained the fifth toe, minus its terminal phalanx, yet of great size and strength, and modified expressly for the purpose of supporting the ponderous body in terrestrial progression.

The fore-foot of the Mylodon more closely conforms, in its essentials, to the type of that of the Unau, inasmuch as the two outer digits (fourth and fifth) were mutilated and clawless; they were, however, developed to the same degree as the fifth digit is in the Megatherium, and for the same end, but probably made little show, externally, in the entire foot. The pollex, however, instead of being rudimental, was fully developed,

* Ostéographie de Paresseux, 4to, p. 22.

though small, in the Mylodon. In the Megatherium this digit is rudimental, as in both forms of existing Sloth; but the bones of the fore-foot correspond more closely with the type of the manus in the Ai; there being, indeed, as regards the digits, only this essential difference, that the fifth, instead of being, like the first, a mere rudiment, was developed to be adapted to progression on the ground. It is most interesting, however, to trace the interchangeable relations between the two above-cited great extinct Megatherioids and the two existing forms of Sloth, respectively.

In regard to other existing Edentata, the *Myrmecophaga jubata*, by reason of the clawless condition of its fifth digit, and the *Myrmecophaga didactyla*, by that of the rudimental pollex as well as fourth and fifth digits, ought to succeed the Sloths as next of kin to the Megatherioid quadrupeds, the interval being due to the difference of carpal structure.

Cuvier has observed that the fore-foot of the *Dasypus gigas* is one of the most extraordinary among quadrupeds; and, he adds, that it alone would give the key to all the anomalies in that of the Megatherium*. But this could only have been affirmed under a misconception of the real nature of those anomalies. In the *Dasypus gigas* the fore-foot is pentadactyle; all the digits are unguiculate, and, in three of them, the claw-phalanges furnish a bony sheath as well as core to the claws; but these belong to the third, fourth and fifth toes, not, as in the Mylodon, to the first, second and third, or, as in the Megatherium, to the second, third and fourth toes; they moreover successively decrease in size from the radial to the ulnar aspect, instead of the reverse proportions which they present in the Mylodon. No doubt the claw on the middle digit is the most developed, as in the Megatherium, and the first and second phalanges of this digit have coalesced; but here ends the particular resemblance between the Megatherium and the great Armadillo, in regard to the bony structure of the fore-foot.

We can state with confidence, what M. Laurillard suggests†, viz. that the fore-feet of the Megatherium, as represented by the skeleton in the Madrid Museum, are not transposed, the right being on the left and the left on the right side, as Cuvier was led to suspect; but that the articulation of those complex parts by the laborious Prosector and Curator Bru, was in the main correct.

The bony structure of the fore-limb of the Megatherium is now, indeed, as completely understood, and the homologies of every constituent bone as exactly defined, as in any existing species of quadruped. And, to the degree in which so important a part of the frame throws light on the whole, the Naturalist may thereby trace the affinities, and the Physiologist infer the habits, of the great extinct beast.

* "La main du *tatou géant* est une des plus extraordinaires qu'il y ait parmi les quadrupèdes, et à elle seule elle expliquerait toutes les anomalies que nous verrons dans celle du Mégathérium."—Ossemens Fossiles, *ed. cit.* tom. viii. p. 242. No qualifying note is appended by the editors to this statement.

† See the note (1) appended by that able anatomist to the chapter on the Megatherium, in the posthumous edition of the 'Ossemens Fossiles,' 8vo, t. viii. p. 355.

Description of the Plates.

PLATE XVIII.

Oblique front view of the skeleton of the Megatherium, on the scale of half an inch to a foot, showing the true position of the manubrium sterni, and the articulation therewith of the clavicles.

PLATE XIX.

Fig. 1. Inner surface of the scapula, one-fourth the natural size.
Fig. 2. Glenoid cavity and acromiocoracoid arch.

PLATE XX.

Fig. 1. Under surface of the right clavicle.
Fig. 2. Front view of the left humerus.
Fig. 3. Back view of the left humerus.
Fig. 4. Head, or proximal articular surface, of the left humerus.
Fig. 5. Distal articular surface of the left humerus.

PLATE XXI.

Fig. 1 Antero-radial surface of the left ulna.
Fig. 2. Proximal end of the ulna.
Fig. 3. Distal end of the ulna.
Fig. 4. Anterior surface of the left radius.
Fig. 5. Proximal end of the radius.
Fig. 6. Distal end of the radius.

The above figures of Plates XX. and XXI. are less than one-fourth the natural size.

PLATE XXII.

Dorsal or upper surface of the bones of the right fore-foot: less than one-half the natural size.

XVI. *On the Anatomy and Physiology of the Spongiadæ.*

By J. S. Bowerbank, *LL.D., F.R.S., F.L.S. &c.*

Received June 17,—Read June 18, 1857.

PART I.—ON THE SPICULA.

Hitherto the Spongiadæ have been classified either by their external form or in accordance with their chemical constituents. In the second edition of Lamarck's 'Anim. s. Vert.,' 138 species are included in the genus *Spongia*, without the slightest reference to their internal structure; and they are divided into seven groups by external form only, the same characters serving also, in a great degree, to discriminate the species.

Fleming, Grant, Johnston, and other modern naturalists, have made their principal divisions depend on their chemical constituents, and have therefore constructed three great divisions as genera:—*Spongia*, composed of keratose fibres unmixed, as it was supposed, with earthy matter; *Halichondria*, formed principally of siliceous spicula; and *Grantia*, having the skeleton composed of calcareous spicula. Included in the second of these divisions are the genera *Tethea*, *Geodia*, *Pachymatisma*, *Spongilla*, *Dysidea*, and *Halisarca*, and these nine genera are all that are contained in Dr. Johnston's 'History of British Sponges.'

Both of these arrangements are very insufficient, and that of Lamarck completely ineffectual, inasmuch as there is no class of animals in which the form varies to so great an extent, according to the difference of locality or other circumstances; and also even when there is a striking normal form, it is rarely thoroughly developed until the animal has reached its full maturity. According to the practice of Lamarck, even under the most favourable circumstances there are frequently recurring difficulties in the determination of the species by this method, as the same forms are found to be common to a great number of sponges, the internal organization of which are widely different to each other. From these causes it is, that no naturalists with whom I have conferred on this subject, have been able to determine with certainty the species of a sponge by the description given by Lamarck in his 'Anim. s. Vert.,' or by those of any other author who has adopted the same method of description, with the exception of perhaps a few very striking species.

The division of the Spongiadæ by their chemical constituents, may serve very well to separate them into primary groups, but they are far too limited to be applied as generic characters. I have therefore for this purpose rejected both systems, and have retained the latter one for the purpose of forming primary divisions only, and I purpose founding the generic characters principally on the organic structure and mode of arrangement of

the skeleton. *Spongilla* differs in no respect from *Halichondria*, as now accepted by naturalists; and the latter, even in the narrow circle of the list of British species, contains at least ten distinct modes of arrangement of the skeleton, each of which is constant and well-defined in its character.

It is not my intention to propose the rejection of any of the well-established genera of my predecessors*, but to confine each genus strictly within the bounds indicated by the peculiar mode of the structure of the skeleton which exists in that species of sponge which is the oldest-established and best-known type of the genus, and to refer all others that may distinctly differ from that type to new genera founded on structural principles.

When I commenced in a similar manner a critical examination of the specific characters of preceding authors, and endeavoured to collect and classify them, I found them to be still more indeterminate than those of class or genera; in truth, it appeared that there was scarcely an approach to a distinct terminology to the science, and that the same author frequently designated the same organ, under different circumstances, by a totally different name; I therefore felt it absolutely necessary, before proceeding to the description of new species, to enter into a thorough systematic examination of the organization of the whole of the species within my reach, and to characterize the organs in such a manner as to render the terms I applied to them definite in their meaning and limited in their application; and in pursuing this object I quickly found an abundance of constant and well-characterized forms and combinations of organization capable of being applied with precision to the purposes of generic and specific descriptions.

I propose, therefore, in the first instance, to characterize the elementary tissues in the following order:—

1. Spicula.
2. Keratode or horny substance.
3. Membranous tissues.
4. Fibrous tissues.
5. Cellular tissues.
6. Sarcode.

And, in the second place, to treat of the organization and physiology in the following order:—

1. The skeleton.
2. The sarcodous system.
3. The interstitial canals.
4. Intermarginal cavities.
5. Dermal membrane.
6. The pores.
7. The oscula.
8. Inhalation and exhalation.

* *Tethea*, *Geodia*, *Dysidea* and a few others are the only well-defined genera that have yet been established.

9. Nutrition.
10. Cilia and ciliary action.
11. Reproduction, gemmules, &c.

And to conclude with observations on

The generic characters;
The specific characters; and
On the method of examination.

In my references to the views of preceding writers regarding the anatomy and physiology of the Spongiadæ, I shall endeavour to correct the errors, rather than to point out the authors of them, feeling satisfied that posterity will care as little about the petty angry discussions concerning the facts and opinions of the present period as we do about those of our ancestors; at the same time I shall endeavour to do justice to the industry and research of preceding naturalists, whose errors of omission are entitled to every possible excuse, when we remember the difficulties they laboured under in the course of their investigations, for want of competent microscopic powers with which to work out the organization of the minute and delicate objects of their research, while we are in full possession of all the advantages of the modern improvements of the microscope, giving a pleasure and facility to our investigations that must have been comparatively almost unknown to our predecessors.

The Spicula.

The spicula are essentially different in character from the fibres of the sponge, although the latter may be equally siliceous with the former. However closely the spicula may be brought into contact with each other or with siliceous fibre, they do not appear to unite or anastomose, while the fibre, whether siliceous or keratose, always anastomoses when it comes in contact with other parts of its own body or of those of its own species.

They differ exceedingly in dimensions; the longest I have seen are the prehensile ones, at the base of *Euplectella cucumer*, Owen, which exceed 3 inches in length.

They are among the earliest organs that are produced in the young sponge. Dr. Grant, in his valuable papers on the development of the Spongiadæ, states that immediately after the ciliated gemmule of the sponge he has described as *Halichondria panicea** has attached itself to a rock or stone, it spreads out into a thin gelatinous-looking spot, and very shortly afterwards there appears a few spicula irregularly disposed in about the centre of the mass†.

In the young gemmules of *Tethea cranium*, while in a very immature condition, they are projected for half their length beyond the surface of the small nucleus of animal matter that exists at the early stage of its development, while in the mature gemmule not a vestige of them is apparent beyond its surface.

In the early stage of their development the spicula appear to consist of a double

* *Halichondria incrustans*, Johnston's 'British Sponges.' † Edinburgh Phil. Journ. vol. xiii. p. 381–3.

membrane, between which the first layer of silex is secreted, and in this condition they present an internal cavity approaching very nearly to the size of their external diameter. In this state they readily bend abruptly in any direction without breaking, as may be seen in Plate XXIII. fig. 1, which represents a porrecto-ternate spiculum from the termination of one of the radial lines of the skeleton at the surface of *Tethea cranium*. This spiculum has been considerably distorted by pressure on the points of the rays at its apex. The deposit of the silex is not continuous and homogeneous, but is produced in successive concentric layers, which it would appear are, at least for a period, equally secreted by the inner surface of the outer membrane and the outer surface of the inner one; for we always find that as the development of the spiculum progresses, the internal cavity gradually becomes less, until finally it exists only as a central canal of very minute diameter in comparison with that of the spiculum itself. These stages of development may often be seen in the spicula of young specimens of *Spongilla fluviatilis*, especially in the spring, when they are growing rapidly. If small fragments of the sponge be slightly charred in the flame of a lamp, and then submitted to microscopical examination, the outer and inner membranes of the spicula will readily be rendered visible (Plate XXIII. figs. 2 and 3); in immature spicula the internal membrane, is represented by a dense black film of charcoal, as in Plate XXIII. fig. 3, while in the mature ones the small central cavity is seen to be lined by so thin a membrane as to afford by its charring a slight brown tinge only to its walls (Plate XXIII. fig. 2). The concentric deposition of the layers of silex or carbonate of lime in the spicula are also readily to be seen (Plate XXIII. fig. 4) in transverse fractures of almost any large spiculum, either siliceous or calcareous, and they present the same aspect as similar sections of either the prismatic cells of shell tissue, or the spicula of a Gorgonia. The amount of silex, and the manner of its deposition in the spicula, is not the same under all circumstances. Where the spiculum is simply required to give strength and firmness to the skeleton, as in the greater number of the Halichondraceous sponges, the whole interior of the spiculum becomes rapidly filled with silex; but where strength is required to be combined with great elasticity and toughness, the mode of deposit is especially adapted to the requirements of the occasion; the amount of the silex deposited is small, and confined wholly to the surface, while the interior appears to be filled with keratode. These laws of deposit will perhaps be best illustrated by my detailing a series of experiments I made by the incineration of the spicula of various sponges in the flame of a small spirit-lamp. I was led to this series of experiments by frequently observing during the course of my investigations the great amount of flexure that many of the large and long spicula would sustain without fracture, and the perfect elasticity with which they regained their original form and position. Thus, in mounting the spicula of *Tethea cranium* in Canada balsam, the long and slender porrecto-ternate defensive spicula projected from its surface would frequently have the shaft bent into a series of sigmoid curves or even loops; and the thickest portion of the same spicula, while in their natural condition, may be bent down to the surface of the sponge, from

which they spring at right angles, so as to form an arc of the third of a circle with perfect impunity. This great flexibility appeared to me to be so incompatible with a purely siliceous structure, that I determined to select the spicula of *Tethea cranium*, more especially to work out this problem, and from the large size of those of the skeleton fasciculi they are more than usually favourable for the purpose. If we view these spicula in their natural condition, mounted in either water or Canada balsam, by transmitted light and a linear power of 150, they present all the usual appearances of solid siliceous spicula; there is a small central tubular cavity, and the substance of the spicula intervening between it and the external surface presents to the eye the linear appearance that characterizes a deposit in concentric circles; and the fractured ends have precisely the same aspect that filaments of the same size of hard dry glue or glass would present to the eye. If these spicula be now burned in the flame of a small spirit-lamp until the combustion is completed and the mass is brought to a white heat, and it be then examined as before, the results are widely different in their aspect; the spicula have become considerably increased in diameter, and instead of being solid, they are now extremely thin tubes of silex lined with a dense and nearly opake film of charcoal, rough and granulated in its appearance. I thought in the first instance that I might have unwittingly selected a fasciculus of young spicula only for burning, and I therefore repeated the experiment, burning only half of the fasciculus and preserving the remainder in an unaltered condition; and on carefully mounting the specimen in Canada balsam, I found the same results precisely; the unburned half of the fasciculus presented all the characters of solidity that I have before described, while the burned half was in perfect unison with the previous results of incineration; and at the junction of the two, the transition from the one state to the other might be readily traced even in single spicula. The external coat of silex in these spicula is so thin and the coat of charcoal with which it is lined so rough and opake, that the thickness of the silex cannot be readily ascertained; but in one of the short, stout, fusiformi-acerate spicula of the dermal coat of the sponge, which is about the same diameter as that of the skeleton spicula, I succeeded in measuring the thickness of the siliceous coat accurately after incineration. The length of the spiculum was $\frac{1}{30}$th of an inch, the greatest diameter $\frac{1}{530}$th of an inch, and the thickness of external siliceous case $\frac{1}{7500}$th of aninch. Plate XXIII. figs. 5 and 6, represent portions of two of the large spicula of the skeleton after incineration.

I have very little doubt that the combustible matter in the interior of these large spicula is really keratode, one of the most elastic and durable animal substances with which we are acquainted. The mode of its deposition within these organs is precisely the same with that presented in all the varieties of keratose fibre with which I am acquainted; and from its concentric arrangement, the nature of the material itself, and its combination with a thin external case of silex, it presents perhaps one of the most admirable natural combinations of strength, elasticity, and durability.

The structure which I have described as prevailing in *Tethea cranium* is not peculiar to that genus. I obtained very similar results from the incineration of the spicula of

Geodia M'Andrewii, BOWERBANK, MS., a new and remarkably interesting species. In this sponge there appeared to be a greater amount of silex secreted in the large skeleton spicula than in *Tethea*, while some of them after incineration were resolved into thin shells of silex, others withstood the operation and retained their form; and some were so completely siliceous, that on plunging them into the drop of water for examination while red-hot from the flame of the lamp, the result was the same as if they had been solid glass rods, and these were cracked and shattered in every direction (Plate XXIII. fig. 8).

I submitted to the same mode of incineration a few of the long siliceous spicula or fibres of *Euplectella aspergillum*, OWEN, burning about half of each fibre, and the result, although somewhat different, was equally satisfactory. The unburned portion appeared perfectly solid, but exhibited the usual trace of concentric structure. The end thoroughly burned became reduced to a thin filament of densely black matter like charcoal, but the junction of the burned and unburned portions was extremely interesting. At this point the action of the heat upon the concentric layers had separated them from each other in the form of a series of thin curved flakes or coats, illustrating the thin concentric structure in a very satisfactory manner; demonstrating that the outer coat of siliceous matter was not the only one, and that probably there were several coats, each containing a sufficient amount of silex in its composition to resist disintegration by incineration (Plate XXIII. fig. 7).

On operating in like manner on the spicula of *Halichondria oculata*, JOHNSTON, little or no alteration was perceptible in the spicula, the inner cavity remaining the same as in the unburned ones, and distinguished only by a slight brown tint, indicating the existence of but a very small amount of animal matter within. This result might be expected; the spicula being, imbedded in the keratose fibre to give it additional firmness and strength, are not required to be elastic; they are therefore short, comparatively stout, and solid in their structure.

A specimen of *Halichondria panicea*, JOHNSTON, burned in the flame of a spirit-lamp to a white heat, exhibited no alteration in the mature spicula, in many of which I could not detect a central tubular cavity; and I presume in these cases the spicula were entirely filled with silex, as in younger spicula it was more or less apparent. When the cavity was very small, the colour had a very faint tinge of brown, and, as in other cases, when the cavity increased in diameter, the amount of colouring matter produced by the incineration of the animal matter within became greater, and deeper in its tint, until in the young and immature spicula the internal cavity occupied the greater part of its diameter, and it became perfectly black and opake; and in one spiculum the gaseous matter generated within expanded one part of the spiculum to such an extent, as to cause it to resemble exactly a hydrometer in form.

The result of the incineration of *Halichondria incrustans*, JOHNSTON, was very similar to that of *Hal. panicea*. The adult spicula remained unaltered, and the central canal was rendered more apparent than it was before.

On burning portions of *Spongilla fluviatilis* and *lacustris*, JOHNSTON, and of *Spongilla*

cerebellata, BOWERBANK, MS., I found the results were similar to those obtained from *Halichondria panicea* and *incrustans*, as regards the spicula of the skeleton; but in the small spinous spicula investing the gemmules of the last-named species there was no apparent alteration, nor could any indication of a central cavity be seen.

The calcareous spicula of *Grantia compressa* withstood incineration better than I expected. The surface was studded with numerous little vesicles generated by the heat, and which interfered with their transparency; but they retained nearly their original colour and proportions; and it may therefore be concluded that they contained so great a proportion of calcareous matter as to prevent their disintegration by heat.

Many of the forms of the spicula are by no means peculiar to the Spongiadæ; but, on the contrary, as I shall hereafter show, their types are frequently to be found in the more highly organized classes of animals, and especially among the Zoophyta, the Tunicata, and the Nudibranchiate Mollusca. They are always of an organic type, never crystalline or angular.

Each of the elongated forms of spicula may be said to be composed of three parts, the base, the apex, and the shaft intervening between the two; and generally speaking, these parts may be readily determined, even when the spicula are isolated.

Each species of sponge has, not one form of spiculum only, equally dispersed throughout its whole substance; but, on the contrary, we find that separate parts have each its appropriate form; and thus we find that three, four, or even more forms often occur in the same individual; and in *Tethea cranium* there are no less than seven distinct shapes. But these differences in structure must not lead us to believe that every strange form of spiculum that meets the eye is a normal one: remarkable variations are often produced for especial purposes in the construction of the skeleton or for other objects; and in some species, *Spongilla lacustris*, for example, the number of odd malformations that are occasionally found is very remarkable. The size also of the normal forms of spicula will often vary to a considerable extent in the same sponge; but if adult, they are always in accordance with the type form, and if not adult, intermediate states of growth are generally present to assist us to form correct conclusions regarding them. The forms thus appropriated to the different parts of the sponge are not always peculiar to certain species, but, on the contrary, they are frequently found to be repeated in other species differing widely in their construction.

The spicula thus appropriate to particular parts of the sponge are uniform in their general characters throughout the whole of the Spongiadæ, and a great portion of them are so well characterized by their form, as to enable the student, when once well acquainted with their peculiarities, to assign each readily to its proper place in the sponge. I purpose therefore, in describing them, to treat of these organs in the following order:—

1. Spicula of the skeleton.
2. Connecting spicula.
3. Defensive spicula.
4. Spicula of the membranes.

5. Spicula of the sarcode.
6. Spicula of the gemmules.

1. *Spicula of the Skeleton.*

The spicula of the skeleton in the siliceous sponges are usually simple, elongate in form, slightly curved, and occasionally more or less furnished with spines. They are either irregularly matted together, collected in fasciculi, or dispersed within or upon the keratose fibres of which the skeleton is to a great extent composed. Occasionally, but not frequently, they assume the triradiate form. In the calcareous sponges, beside the simple elongate form, the triradiate spicula are found in abundance.

All the elongate forms of spicula of the skeleton are subject to extreme variety in length. In some species they maintain a great degree of uniformity, while in others they vary to a very considerable extent, according to the necessities arising from the mode of the construction of the skeleton.

The commonest form of skeleton spiculum is perhaps the

Acerate.—Of the same diameter for the greater part of the length of the shaft, but decreasing equally near each termination, and ending acutely at both.

The proportions of length and diameter vary to a considerable extent in this form. In *Halichondria panicea*, Johnston, it is of about the medium proportions (Plate XXIII. fig. 9, *a*). In *Spongilla fluviatilis* it is much shorter and stouter (Plate XXIII. fig. 9, *b*).

Fusiformi-acerate.—Having the greatest diameter at the middle of the shaft, and decreasing gradually to each acute termination. *Halichondria coccinea*, Bowerbank, MS. (Plate XXIII. fig. 10).

Inflato-fusiformi-acerate.—Fusiformi-acerate, with a globular inflation at the middle of the shaft. This form of spiculum is abundant in the skeleton of *Isodictya anomala*, Bowerbank, MS. A new British sponge. It is sometimes extremely fusiform in shape (Plate XXIII. fig. 11).

Acuate.—Of the same diameter from the hemispherically-terminated base to near the acutely-terminated apex. *Halichondria Alderi*, Bowerbank, MS. (Plate XXIII. fig. 12, *a*). *Hymeniacidon caruncula*, Bowerbank, MS. (Plate XXIII. fig. 12, *b*).

Fusiformi-acuate.—Having the largest diameter near the middle of the shaft, and decreasing thence gradually towards the hemispherical base and the acute apex. *Halichondria crustula*, Bowerbank, MS. (Plate XXIII. fig. 13).

Attenuato-acuate.—Decreasing gradually in diameter from the hemispherical base to the acutely terminated apex. *Halichondria infundibuliformis*, Johnston (Plate XXIII. fig. 14).

Flecto-attenuato-acuate.—Attenuato-acuate bent suddenly near the base of the spiculum. *Halichondria infundibuliformis*, Johnston (Plate XXIII. fig. 15). In other species of sponges, and in other forms of spicula, the bending near the base is not so abrupt, but it is still characteristic and constant in the species, as for example in the flecto-acuate spicula of *Halichondria variantia*, Bowerbank, MS. (Plate XXIII. fig. 16).

CYLINDRICAL.—Having the shaft of the same diameter throughout its length, and terminating at each end hemispherically, as in *Pachymatisma Johnstonia*, BOWERBANK (Plate XXIII. fig. 17).

FUSIFORMI-CYLINDRICAL.—Having both terminations hemispherical, and the shaft gradually increasing in diameter to its middle. *Pachymatisma Johnstonia*, BOWERBANK (Plate XXIII. fig. 18).

ATTENUATO-CYLINDRICAL.—Terminating hemispherically at both ends, but the shaft slightly decreasing from the base to the apex. *Pachymatisma Johnstonia*, BOWERBANK (Plate XXIII. fig. 19).

FUSIFORMI-ATTENUATO-CYLINDRICAL.—Both terminations being hemispherical, the fusiform shaft has a much smaller diameter towards its apex than it has at its base. From *Tethea robusta*, BOWERBANK, MS. A new species from Australia in the British Museum (Plate XXIII. fig. 20).

BICLAVATED CYLINDRICAL.—The shaft equally cylindrical, with gradually inflated terminations. The inflations are almost as great as that of a spinulate spiculum, but without sphericity (Plate XXIII. fig. 21). From a new and undescribed species from Australia, Bowerbank Collection.

INEQUI-BICLAVATED CYLINDRICAL.—The shaft attenuated from the base to the apex, with clavated terminations of unequal diameters (Plate XXIII. fig. 22). From *Pachymatisma Johnstonia*, BOWERBANK.

FRANKLIN INSTITUTE LIBRARY.

ANGULATED INEQUI-BICLAVATED CYLINDRICAL.—This singular angulated form does not appear to be purely accidental, as I have found other instances of similar angulation at the middle of the shaft in other sponges, and the angle in each instance has been as nearly as possible at the same spot in the shaft. *Pachymatisma Johnstonia*, BOWERBANK (Plate XXIII. fig. 23).

SPINULATE.—Shaped like a pin, having the same diameter from the spherical base to very near the acutely terminated apex. *Halichondria carnosa*, JOHNSTON (Plate XXIII. fig. 24).

FUSIFORMI-SPINULATE.—The base being spherical, the shaft more or less fusiform and terminated acutely. *Halichondria suberea*, JOHNSTON (Plate XXIII. fig. 25).

ATTENUATO-DEPRESSO-SPINULATE.—Having the basal inflation considerably depressed, and the shaft gradually attenuated from the base to the apex. From a new species of sponge from Ash Island, in the cabinet of Mr. THOMAS INGALL (Plate XXIII. fig. 26).

ENORMI-SPINULATE.—Having the spherical inflation slightly within the basal portion of the shaft of the spiculum. *Halichondria celata*, JOHNSTON (Plate XXIII. fig. 27).

FLEXUOUS.—Having the shaft of the spiculum curved repeatedly (Plate XXIII. fig. 28). *Halichondria ventilabrum*, JOHNSTON.

ENSIFORM.—Expanding towards the apex, but terminating acutely; so that the outline has more or less the form of the blade of a sword. Sponge unknown (Plate XXIII. fig. 29).

The spicula of the skeleton in some species of siliceous sponges are more or less

furnished with acutely conical spines, which are irregularly dispersed over the whole or a portion of the spiculum, and they are therefore said to be,—

ENTIRELY SPINED.—When the spines are equally dispersed over the spiculum from the base to the apex (Plate XXIII. fig. 30). *Halichondria incrustans*, JOHNSTON.

BASALLY SPINED.—When the spines do not occupy more than about one-third of the basal portion of the spiculum (Plate XXIII. fig. 31). *Halichondria Ingalli*, BOWERBANK, MS., a new British sponge.

MEDIALLY SPINED.—When the spines occupy only about one-third of the middle of the spiculum (Plate XXIII. fig. 32). *Halichondria Ingalli*, BOWERBANK, MS.

APICALLY SPINED.—When the spines occur only at and near the apex of the spiculum: from an undescribed sponge, locality unknown (Plate XXIII. fig. 33).

TERMINALLY SPINED.—When the spines occur near both the base and apex of the shaft of the spiculum, but not at the middle: from an undescribed species of sponge, locality unknown (Plate XXIII. fig. 34).

TRIRADIATE SPICULA.—These forms among the siliceous sponges are occasionally found imbedded among the other spicula of the skeleton at the angles of the reticulation; and the radii in nearly all the specimens I have seen terminate acutely. But it is in the calcareous sponges, *Grantia* of FLEMING, they are essentially the spicula of the skeleton. They are,—

EQUIANGULAR TRIRADIATE.—Having the three attenuating rays in the same plane, and the intervening angles equal, or very nearly so (Plate XXIII. fig. 35). *Grantia compressa*, FLEMING.

RECTANGULAR TRIRADIATE.—Having the three attenuating rays in the same plane, two of them forming a straight line, and one being projected from the middle of the line, forming right angles to it. Abundant in the base of the ciliary fringe of the mouth of the cloaca of *Grantia tessellata*, BOWERBANK, MS. A new British species (Plate XXIII. fig. 36).

Both the above forms are subject, even in the same species, to considerable variations, arising from the necessities of their situation in the skeleton. The radii also vary greatly in thickness and length in different species: the stoutest form I have seen occurs in a new species of calcareous sponge from Africa, a spiculum of which is represented (Plate XXIII. fig. 37).

EQUIANGULAR SPICULATED-TRIRADIATE.—Having the three rays in the same plane with the intervening angles equal, and a fourth ray projected from the basal junction of the radii at right angles to their plane. This is the only case in which I have found this form of spiculum in a siliceous sponge, *Halina Bucklandi*, BOWERBANK, MS. A new British species. But this form is very common in the calcareous sponges, where it appears as a defensive organ; and in treating of it as such I have given my reasons for not designating it as a quadriradiate spiculum (Plate XXIII. fig. 38).

BIANGULATED QUADRIRADIATE.—Having two radii projected from a common basal point, in one plane forming an angle of about 90°, and the other two projected in a similar manner in an opposite direction in a second plane at right angles to the first one.

This singular form is associated with the spiculated triradiate one in the skeleton of *Halina Bucklandi*, BOWERBANK, MS. (Plate XXIII. fig. 39).

TRIFURCATED PATENTO-BITERNATE.—Consisting of a short stout shaft, each end being furnished with three short equiangular radii passing off at right angles to the shaft, and each having its termination trifurcated (Plate XXIII. fig. 40, a side view, and fig. 41 a view of one end of a spiculum). This singular form occurs in the tortuous excavations of probably a small annelid in a soft limestone, the sponge lining the cavities in a manner similar to *Halichondria celata*, JOHNSTON. The skeleton consists entirely of this singularly complicated form of spiculum: I am indebted to my friend Mr. THOMAS INGALL for a portion of the sponge.

Connecting Spicula.

The connecting spicula are not necessarily a part of the skeleton, they are a subsidiary portion of it occurring under special circumstances, in a few genera only, such as *Geodia*, *Pachymatisma*, and other sponges which have a thick crustated surface, which they serve to support and retain in due connexion with the mass of the animal beneath. The triradiate apices also serve to construct areas in which are situated the proximal orifices of the intermarginal cavities, which are imbedded in the crustated surface of the sponge. The normal form of these spicula is very different from that of the spicula which constitute the general mass of the skeleton, and they are far more complex and varied in their structure. They usually have a long, stout, cylindrical, or attenuated shaft, terminating either acutely or hemispherically at the base, while the apex is divided into three stout equiangular radii, which assume in different species a considerable amount of variety as regards form and direction. The triradiate apices are usually cemented firmly to the inner surface of the crustated coat of the sponge, while the stout and elongated shaft is intermingled with and firmly cemented by keratode to the general mass of the skeleton. From the trifid nature of the apex, I have designated the seforms as ternate spicula, prefixing such terms as may best serve to distinguish them individually in accordance with their permanent variations from each other. The prefixed designations of the spicula must necessarily in some measure be arbitrary, as the differences in the degree of the expansion of the radii cannot be strictly defined; and although the forms are well characterized in each species, yet even within these bounds a slight degree of variation, arising from the local necessities of the case, will occur. The ternate spiculum, therefore, as a general designation, may be said to be an elongate spiculum, with a triple apical termination. These spicula are not confined to the office of connecting only, but are also found among the defensive ones, as will be hereafter shown.

PORRECTO-TERNATE.—Having the terminal radii projected forward at an angle to the shaft of less than 45 degrees.

The best type of this form is in *Tethea cranium*, JOHNSTON, where it is a defensive spiculum as well as a connecting one (Plate XXIV. fig. 10).

EXPANDO-TERNATE.—Having the terminal radii projected forward at angles varying from 45 to 60 or 70 degrees to the long axis of the shaft. Plate XXIII. fig. 42, represents

an attenuated spiculum from *Pachymatisma Johnstonia*, and Plate XXIII. fig. 43, a cylindro-ternate spiculum from the same sponge.

PATENTO-TERNATE.—Having the terminating radii disposed at, or nearly at right angles to the shaft of the spiculum, the curves of the radii being usually more or less inclined backwards towards the base of the shaft. Plate XXIII. fig. 44, represents a spiculum from *Geodia M^c^Andrewii*, BOWERBANK, MS. A new species from Vigten Island, coast of Norway.

Patento- and expando-ternate spicula are both subject to variations dependent on the form of the shaft, which in some cases is attenuated from the apex to the base, where it terminates acutely; or the shaft is cylindrical, subfusiform or spinulate: in such cases, we should designate them as spinulo-expando-ternate, or otherwise, as might be requisite for accurate distinction of the form.

RECURVO-TERNATE.—The terminating radii, recurved from about 100 to 140 degrees from the apical line of the axis of the shaft. The curves of the radii are always more or less inclined towards the base of the shaft of the spiculum (Plate XXIII. fig. 45). From *Geodia Barretti*, BOWERBANK, MS. Vigten Island, Norway.

FURCATED ATTENUATO-PATENTO-TERNATE.—The radii of the ternate apex is not always simple; in some species, as in *Pachymatisma Listeri*, BOWERBANK, MS., a new species from Madeira, and in *Geodia Barretti*, BOWERBANK, MS., from Vigten Island, Norway, each of the rays have bifurcated terminations in the same plane as the primary radii, as represented in Plate XXIII. figs. 46 and 47, the former being erect, and the latter having the plane of the radii presented to the eye. From *P. Listeri*, BOWERBANK, MS.

SPICULATED DICHOTOMO-PATENTO-TERNATE (Plate XXIII. fig. 48), is a still more complicated form, the radii of the bifurcations each terminating again dichotomously; but the secondary bifurcations are not all of them in the same plane as the primary ones, a portion of them being at right angles to it, and the shaft is also carried through the common central base of the whole, giving it a spiculated form, as represented in the figure. This prolongation of the shaft through the common base of the radii of the ternate spicula is not confined to the one described above, but it does not appear to be a normal form.

I have never seen a quaternate spiculum associated with the connecting spicula, in which all the radii were equi-divergent; in all such cases three appear to represent the ternate type of spiculum, and the fourth, or supplemental one, is a continuation of the axial line of the shaft, which passes through the united bases of the ternate portion of the spiculum. I have therefore designated these forms as spiculated ternate rather than quaternate.

These spicula are rather anomalous in their character. They frequently, but not universally, accompany the true connecting spicula; the ternate apices do not usually reach the under surface of the crustated coat; in *Geodia Barretti* and some other species, in which they occur but occasionally, they partially fulfil the office of connecting spicula. There is a constant and striking difference in the proportions of the

true and the pseudo-connecting spicula, if we may so term them; the proportions of the former are generally stout and strong, while those of the latter are always long and very much more slender.

SPICULATED PORRECTO-TERNATE.—Having three equidistant porrect terminal rays, and a fourth or central one in a line with the axis of the shaft (Plate XXIII. fig. 49). From *Geodia Barretti*, BOWERBANK, MS., from Vigten Island, Norway.

SPICULATED RECURVO-TERNATE.—Having three equidistant recurved radii, and the central terminal one porrect in the line of the axis of the shaft of the spiculum (Plate XXIII. fig. 50). From *Geodia Barretti*, BOWERBANK, MS., from Vigten Island, coast of Norway.

The central porrect terminal ray is often more or less deflected from the axial line of the shaft, as in Plate XXIII. fig. 51; and occasionally, in the simple recurvo-ternate form, one of the three rays will be bent upward, even to a greater extent than is represented in fig. 53; but these, it must be recollected, are but accidental variations in form.

The shafts of the recurvo-ternate forms of spicula are much less in diameter than those of the patento or expando-ternate ones from the same sponge, and they are frequently very long and exceedingly attenuated.

Prehensile Spicula.

Spicula projected from a sponge as a means of attachment to other bodies.—I know of but one form of this description of spiculum, an exceedingly elongated, fusiformi-acerate one, with a stout recurvo-quaternate apex. It occurs at the base of *Euplectella aspergillum* and *E. cucumer*, OWEN. The long attenuated basal portions of the shaft being without spines, are incorporated with the longitudinal fasciculi of the skeleton, while the apical portions of them are projected from the base of the sponge, and embrace and hook on to any extraneous mass near which it may be situated; and this free portion is thickly beset with strong acutely conical spines, reflected at about the same angle and in the same direction as the radii of the quaternate apex, and to which they are auxiliary as prehensile organs; and as we proceed from the apex towards the central portion of the spiculum, the spines successively decrease in length, until at about one-third of the length of the spiculum from its apex they become obsolete. I am indebted to my friend Dr. ARTHUR FARRE for the specimen figured of this singular and interesting form of spiculum; and the only sponge in which they have been found in a perfect state, is the delicate and beautiful one designated by Professor OWEN *Euplectella cucumer*. They occur in great profusion, embracing the mass of matter at its base in every direction. I propose, therefore, to designate this form as an apically spined recurvo-quaternate spiculum (Plate XXIII. fig. 53: *a*, the apical portion of the spiculum; *b*, a portion from that part of the shaft at which the spines become obsolete).

As a solitary instance of the occurrence of a spiculum, so singular in its form and so unusual in its application, and being, like the connecting spicula, to a considerable extent incorporated with the skeleton of the sponge, I have thought it advisable to describe it as an auxiliary form, rather than to consider it as the type of a class.

Defensive Spicula.

There are two classes of defensive spicula:—

1st. Those of the exterior,
2nd. Those of the interior of the sponge.

They are neither of them necessarily present in every species, nor are they confined to particular genera, but occur occasionally, and in certain species of various genera, apparently as the necessities of the animal may render their presence requisite. If the exterior of the animal be amply supplied with them, the interior rarely possesses them. Their office is evidently to defend the sponge from the attacks of predacious animals that would otherwise very probably destroy it; and thus it is that the external defensive spicula are frequently of more than the usual length and strength of these organs. They are projected for about half or two-thirds of their length, at various angles from the surface of the sponge, apparently with the object of meeting the attacks of the larger class of depredators; but as between these large spicula the smaller tribes of annulate animals would readily insinuate themselves, there is frequently a secondary series of defences, consisting of innumerable short, finely-pointed spicula, the *apices* of which are projected a short distance only beyond the surface of the dermal membrane, thus rendering the progress of the smaller and more insinuating enemies extremely difficult, if not impossible. In young sponges, as in *Spongilla fluviatilis* and others, the office of external defensive spicula is frequently performed by the continued extension of the radial lines of the skeleton, the terminal spicula of which often project to more than the extreme length of a spiculum beyond the surface of the dermal membrane.

When the defensive spicula are internal they assume a different character from the external ones. The most common form under these circumstances is that of a short, stout attenuato-acuate spiculum, profusely and entirely spined; they are firmly based in the substance of the skeleton; and the greater portion of their length is projected at various angles from the sides of the interstitial canals and cavities of the sponge. They would thus render the passage of minute annelids and other small enemies extremely difficult; and in one instance, the mode in which the protection of the interior of the sponge is provided for is very remarkable and curious. Large spinulo-recurvo-quaternate spicula with attenuating radii are grouped together on the angles of the network of the skeleton, and are projected in a radiating manner into the cavities of the interior of the sponge, forming a most effectual prevention to the passage of any small animal. The occurrence of this complicated and beautiful form of spiculum is a singular deviation from the normal mode of defence, and almost induces the belief that it was intended that such intruders as effected an entrance were meant to be retained, and their decomposed particles appropriated to the nutrition of the sponge. In other cases, where no definite form of defensive spiculum forms a part of the sponge, the office of those organs is frequently performed by the projection of spicula similar to those of the skeleton into the canals and cavities of the interior.

FUSIFORMI-ACERATE.—*Geodia Barretti*, BOWERBANK, MS. On this remarkably fine species of *Geodia* this form of defensive spiculum occurs in parts in such abundance, that they completely cover and obscure the surface of the sponge, from which they project nearly the whole of their length, the proximal ends of many of them scarcely passing through the dermal crust of the sponge. This sponge has also a secondary series of defensive spicula, of the same form as the larger ones; the latter often exceeding $\frac{1}{8}$th of an inch in length, while the secondary spicula do not exceed $\frac{1}{64}$th of an inch in length. For the form of this spiculum see Plate XXIII. fig. 10.

ATTENUATO-ACUATE: ENTIRELY SPINED.—*Dictyocylindrus ventilabrum*, BOWERBANK, MS. This short form of spiculum is of very frequent occurrence in the interior of sponges of several different genera. They are usually profusely spinous, and especially at the base, which is firmly imbedded in the keratode of the skeleton. The spines are irregularly dispersed over all parts of the shaft, to the very apex of the spiculum; they are projected into the interstitial cavities and canals of the sponge at all angles to the axis of the skeleton on which they are based, and no degree of regularity exists in their mode of dispersion. In some sponges they occur in considerable numbers; but in others, where the animal is well protected by the abundance of the large radial spicula, they are few in number, and are not to be detected without a very careful search (Plate XXIV. fig. 1).

ACUATE: ENTIRELY AND VERTICILLATELY SPINED (Plate XXIV. fig. 2).—This form of spiculum is one of the most remarkable and beautiful of its tribe. I have found it in two distinct species of sponge from the West Indies. In one it is irregularly dispersed, and in the other it is collected into radiating groups. The form of the spiculum is short, stout, and regularly acuate, having the acutely-conical spines arranged in nearly equidistant rings of a single series each, from the base to the apex of the spiculum.

CYLINDRICAL: ENTIRELY AND VERTICILLATELY SPINED (Plate XXIV. fig. 3).—I am not acquainted with the sponge whence this beautiful spiculum came. I found it in the refuse matter from the base of a specimen of *Oculina rosea*, from the South Seas. The shaft of the spiculum, from end to end, has equidistant rings of single series of acute conical spines, and the base and apex of the spiculum are each equally crowded with spines. I have arranged it as a defensive spiculum, from its near approximation to the characters of the spiculum last described; but it is subject to the doubt whether it may not ultimately prove to have belonged to the skeleton, as we have in *Halichondria incrustans*, JOHNSTON, entirely spined acuate spicula forming the skeleton, the characters of which are so closely allied to the attenuato-acuate defensive spicula so common in the interior of some sponges, that had we found but a single spiculum of the skeleton of that sponge, we should very naturally have concluded it to have been an internal defensive spiculum.

SPINULO-RECURVO-QUATERNATE.—I have found this remarkable form of spiculum in one sponge only, and I am indebted to my friend Mr. THOMAS INGALL, in whose cabinet it is, for my knowledge of it. They occur in great profusion in the cavities of the sponge, clusters of them consisting frequently of as many as twelve or fifteen radiate from the

angles of the reticulations of the skeleton into the interstitial cavities of the sponge. The shaft is stout and cylindrical, with the spherical base of a spinulate spiculum; and in a fully-developed condition the apex is formed of four equiangular attenuated incurved radii (Plate XXIV. fig. 7). The gradual development of this form of spiculum is interesting and very instructive. In an early stage of its development it has the appearance of a slender inequi-biclavate cylindrical spiculum (as represented in Plate XXIV. fig. 4); in the next stage there is a slight indication of the spinulate base, and a corresponding amount of expansion of the apex, but no indication of the radii (Plate XXIV. fig. 5). From this state to the next well-marked stage of growth (represented in Plate XXIV. fig. 6) the progressive development of the radii may be readily traced, and thence to the adult condition represented in Plate XXIV. fig. 7.

In its fully-developed state we find a great increase in its size in every respect; the base becomes fully developed and globular, and the radii elongated to a very considerable extent.

Fusiformi-porrecto-ternate.—These spicula form the greatest portion of the fasciculi of defensive spicula with which the external surface of *Tethea cranium* is armed. They are very long and slender, frequently exceeding a quarter of an inch in length, with a diameter of $\frac{1}{1415}$th of an inch at the thickest portion of the shaft. The ternate radii are projected from the apex of the shaft at about an angle of 20° from its axis, and are about $\frac{1}{150}$th of an inch in length (Plate XXIV. fig. 10). The shafts of these spicula possess a considerable amount of flexibility; and as the central cavities of the radii, excepting at the apices, are often very large, it is probable that they possess flexibility to a certain extent also; and this appears to be the case from the singular contortions that they frequently exhibit. One of these accidents is well represented (Plate XXIII. fig. 1), which exhibits the distal end of one of these spicula. In this case it is evident that a violent downward pressure has bent the ray, while in a young condition, in no less than six different places without destroying it, or indeed materially injuring its efficiency as a means of defence. The slenderness of the shaft of this as well as of the recurvo-ternate spicula which accompany it, as compared with those of the skeleton, which are occasionally protruded along with them, is probably designed by nature to allow of their yielding more or less to pressure from without. If we burn in the flame of a spirit-lamp a thin slice at right angles to the surface of the sponge, so as to consume the whole of the animal matter enveloping the spicula and char that within, the beautiful adaptation of these spicula to their especial office is rendered apparent. When immersed in Canada balsam and viewed by transmitted light with a power of about 150 linear, we often find the lower portion of the spiculum, which was seated in the sponge with a small tubular central cavity which gradually becomes larger, until it occupies by far the greater part of the diameter of the shaft, in that part of it which is projected beyond the dermal membrane, and it terminates in a large bulbous cavity at the base of the ternate radii of the apex. In the mature spicula three small tubular cavities traverse the radii from the base to the apex, having a diameter not exceeding

one-tenth of that of the ray at any part, while that of the apex of the shaft occupies about nine-tenths of its diameter at that point; while the defensive points are thus strengthened as much as possible to adapt them to their especial office, the shaft is so constructed as to possess the greatest amount of combined strength and flexibility. Plate XXIV. fig. 11 represents the head of a ternate spiculum thus charred. In less-developed spicula we often find the central cavity of the ternate ray comparatively large and gradually decreasing to the apex, and in older spicula than that first described, the central cavity of the shaft is sometimes comparatively small near its apex; but if so, we generally find that it expands rapidly as we proceed lower, so that in this case it is only a transference of the elasticity to a lower portion of the shaft. Plate XXIV. fig. 8 exhibits the earliest stage of development of the porrecto-ternate head of the spiculum; fig. 9 a more advanced stage of growth; and fig. 10 a mature and fully developed spiculum.

Fusiformi-recurvo-ternate spiculum.—This form of defensive spiculum occasionally accompanies the porrecto-ternate ones of the defensive fasciculi of *Tethea cranium*. The length and proportions of the shaft of the former is very much the same as those of the latter. The recurvate apex of this spiculum undergoes a progressive development, which does not appear to commence until after a great extent of the length of the slender flexible shaft has been produced, when an enlargement of the apex of the shaft takes place, and the rudiments of the stout recurvate radii appear as represented by fig. 12, Plate XXIV., and between this and the fully-developed form, fig. 13, all the intermediate gradations of development may be observed among the spicula of young specimens of the sponge. The two figures are drawn by the same power, 260 linear, and the difference in size between the young and the fully-developed spiculum is very remarkable.

In the calcareous sponges, *Grantia* of Fleming, we find the defensive spicula which are projected into the great cloacal cavities emanating from the basal junction of the radii of the ordinary triradiate spicula of the skeleton, and they are frequently of a different form to that of the radii of the skeleton spicula, and in most of the sponges of this class they form very effective specific characters. The production of a spicular ray from the centre of the ordinary triradiate skeleton spiculum often seems to cause an extra development of one or more of the radii of the latter, and occasionally the basal radii are bent or distorted in a manner rarely observed in the simple skeleton spicula.

Spiculated equiangulated triradiate.—When the spicular ray is of the same form and at right angles to the common plane of the basal radii (fig. 14, Plate XXIV.), from *Grantia nivea*, Johnston.

Spiculated rectangulated triradiate.—This form of defensive spiculum is occasionally found intermixed with the equiangulated triradiate forms in several species of *Grantia*.

Ensiform spiculated equiangulated triradiate.—The spicular ray is at right angles to the common plane of the basal radii, but not of the same form. In *Grantia ensata*, Bowerbank, MS., a new species from the Island of Sark, it is very much longer and stouter than the basal radii, and its diameter is considerably increased in the distal third

of its length, giving its outline very much the form of an ancient sword (fig. 15, Plate XXIV.). In *Grantia tessellata*, BOWERBANK, MS., a new species from the Island of Sark, the spicular ray is short, very stout, and curved throughout its whole length in the form of a sabre, as represented by fig. 16, Plate XXIV.

EQUIANGULATED SPICULATED TRIPODATE.—When the basal radii are projected backward so that their apices only are in the same plane, and the spicular ray at right angles to that plane. The short spicular ray in this case is not based on a triradiate skeleton one, but the whole spiculum is essentially a defensive one only. They occur in the lining membrane of the cloaca of *Grantia nivea*, and are very minute (fig. 17, Plate XXIV.).

EQUIANGULATED TRIRADIATE: UNIRADIALLY SPINED.—I obtained a considerable number of this form of spiculum from the dissolution in nitric acid of a small fragment of a parasitical sponge, in the collection of the late Mr. CHARLES STOKES. I have not seen it *in situ*, but I have very little doubt from its structure that the spiculated ray is a defensive one, while the two spineless rays formed part of the skeleton (fig. 18, Plate XXIV.).

ATTENUATO-CLAVATE: INCIPIENTLY SPINED.—The enlargement of the base of this spiculum is not spherical as in a spinulate form, but it expands more or less gradually and is usually exaxial. They are projected in abundance into all parts of the interstitial cavities of a new species of British sponge, *Hymeniacidon clavigera*, BOWERBANK, MS. (Plate XXIV. fig. 19).

EQUIANGULAR TRIRADIATE: VERTICILLATELY SPINED.—This beautiful spiculum was found among minute fragments of various sponges scraped from the bases of specimens of *Oculina rosea*. I have never found verticillately spined sponge spicula under any other character than that of defensive spicula, and I have therefore arranged this one as such until further information shall be obtained regarding it (fig. 20, Plate XXIV.). Other forms are frequently found disposed as defensive spicula, but as they do not differ in shape from the skeleton spicula already described and figured, it is unnecessary to figure them again.

Spicula of the Membranes.

There are two distinct classes of spicula appropriated to the membranous tissues of sponges. The office of the first of these is simply to strengthen and support those delicate tissues when necessary, and to communicate to them a certain amount of tension when it is required. The forms are few in number, and their structure comparatively simple.

The office of the second class is that of assisting in the retention of the sarcode on the interstitial and other membranous structures. They are usually minute in size, and often very complicated in form.

I propose to designate these organs as,—

1st. Tension Spicula.
2nd. Retentive Spicula.

Tension Spicula.

In some species of sponges the dermal membrane is without spicula especially appropriated to it, and it then appears, as in *Spongilla fluviatilis*, to be a simple translucent membrane filling up all parts of the network of the external surface of the skeleton, and closely adhering to it; but the membranous areas thus formed are devoid of peculiar forms of spicula. In other cases, as in *Spongilla lacustris*, we find spicula dispersed more or less abundantly over the whole of the surface of the membrane, which are entirely unconnected with the skeleton, and give to the dermal membrane a degree of firmness and tension that it would not otherwise possess. I therefore propose to designate spicula thus occurring in the membranes, whether dermal or interstitial, as tension spicula.

These spicula are sometimes of the same form as those of the skeleton, as in *Halichondria panicea*, JOHNSTON, where we find them thickly, but irregularly dispersed on the inner surface of the dermal membrane; or they have a separate and distinct form, as in *Halichondria incrustans*, JOHNSTON, where they are slender and cylindrical with mucronate terminations, while those of the skeleton are of a stout acerate form. In both cases they are exceedingly numerous, and are evidently designed by nature to strengthen and support the dermal membrane. In the interstitial membranes the same object is frequently attained by the incipient skeleton spicula, and we often find either very young and minute skeleton spicula in the membranous areas of the network of the skeleton, or there will be one or more spicula very little less in size than those of the skeleton, imbedded in the surface of the membrane, but quite unconnected with the surrounding skeleton; or occasionally connected by one termination only, but ultimately by the development of other spicula, becoming incorporated with, and forming part of the skeleton. And it is not in the Halichondraceous sponges only that the tension spicula occur, for we find them abundantly dispersed in the dermal membrane of one of the Turkey sponges of commerce, the honey-comb sponge of dealers, in which siliceous spicula play a very subordinate part in the construction of the skeleton.

FUSIFORMI-ACERATE: ENTIRELY SPINED (Plate XXIV. fig. 21).—This form of spiculum occurs abundantly in the dermal and interstitial membranes of *Spongilla lacustris*, JOHNSTON.

FUSIFORMI-ACERATE: TRUNCATEDLY SPINOUS (Plate XXIV. fig. 22).—Abundant in *Spongilla alba*, CARTER, in both the dermal and interstitial membranes.

MUCRONATO-CYLINDRICAL (Plate XXIV. fig. 23).—The dermal membrane of *Halichondria incrustans*, JOHNSTON, is abundantly furnished with large flat fasciculi of this form of spiculum. They are as long as those of the skeleton, but not above half their diameter; they are entirely destitute of spines, while the spicula of the skeleton are covered with those organs.

TERMINALLY SPINED SUBFUSIFORMI-CYLINDRICAL.—This form of spiculum is abundant in the dermal membrane of *Halichondria nigricans*, BOWERBANK, MS., where it occurs in irregular fasciculi. It is as long as the spicula of the skeleton, but has not quite so great a diameter, and is distinctly different in its form.

TUBERCULATED FUSIFORMI-CYLINDRICAL (Plate XXIV. fig. 24).—These minute spicula are profusely dispersed on the inner surface of the dermal and interstitial membranes of *Pachymatisma Johnstonia*. They are short and stout, and are covered very irregularly with ill-defined tubercles. They vary very considerably in form and proportions. Their average dimensions are, length $\frac{1}{857}$th of an inch, diameter $\frac{1}{5000}$th of an inch.

INFLATO-CYLINDRICAL (Plate XXIV. fig. 25).—This form of spiculum is very minute. It is slightly curved, and has a single, well-defined bulbous inflation near the middle of the shaft, but in this respect, as well as in size, there is, comparatively, a considerable amount of variation. The normal condition of the inflation is equidistant from the ends of the spiculum, but in some cases it is not more than a third of the length of the spiculum from one end of it. The only sponge in which I have found this form is *Halichondria ficus*, JOHNSTON, where it occurs in the dermal membrane in great profusion.

TRICURVATO-ACERATE (Plate XXIV. figs. 26, 27, and 28).—This form of spiculum has always three curves in the course of its length, one at the centre of the shaft, and one near each termination, the terminal ones curving in the same direction, and always opposite to that of the central curve.

These spicula vary greatly in form and proportions in different sponges, and frequently even in the same species. The normal form is that of three curves of about equal value (Plate XXIV. fig. 26), but sometimes, as in fig. 27, the central curve is very much the larger of the three, while in fig. 28 we find the extreme condition of the form, the spiculum being comparatively straight, with a very small curve in the centre of the shaft, and the terminations exhibiting only the rudiments of curves in an opposite direction to the middle one. They are usually very much more slender than the spicula of the skeleton, and are comparatively of rare occurrence in every species in which I have found them. I have never seen them *in situ* with the terminal curves elevated above the surface of the membrane, but always reposing on one side, with all parts of the shaft closely attached to its surface. The three forms figured are from the same specimen of sponge.

UNICURVO-CRUCIFORM (Plate XXIV. fig. 29).—This form occurs abundantly on the membrane lining the great cloacal cavities of *Grantia nivea*, JOHNSTON. The axial radii are disposed very nearly in the direction of the long axis of those organs, and the curves formed by the lunate radii always have their points towards the mouth of the cloaca.

FALCATO-ACERATE (Plate XXIV. fig. 30).—This form is abundant in a small species of *Grantia* from Australia, which is found on several species of Fuci in the collections brought home by Dr. HARVEY. The sponges do not frequently exceed the eighth of an inch in length.

BICURVO-ACERATE (Plate XXIV. fig. 31).—This form is from a small parasitical *Grantia* from Algoa Bay, in my collection. The sponge is about the size of a large pea, and is not uncommon on Zoophytes from that locality.

Foliato-peltate Spicula.

These spicula have the shaft exceedingly short and conical; the basal termination being acute, and the shaft dilating rapidly to its distal end, to the extent of an angle

of about 15 or 20 degrees. The apex of the spiculum expands into a large, more or less circular, disc or shield, having in the fully developed state an extremely sinuous or foliated margin; the plane of the shield or disc being at about right angles to the line of the shaft, and having the under side thickly studded with tubercles, which are separate in the young spicula, and more or less confluent in the fully developed ones (Plate XXIV. figs. 32, 33, 34, 35, 36, 37, and 38).

In an early stage of its development, the peltate apex of the spiculum is irregularly circular, and entirely devoid of the complex and beautiful sinuous foliations that render the adult spicula such elegant objects (Plate XXIV. fig. 32). As the development proceeds, it assumes a trilobular shape, and the margins are slightly indented or serrated (fig. 33).

In a further advanced condition, the sinuation of the margin becomes deeper and more complex, as represented in figs. 34 and 35, until at last it becomes, in the fully developed peltate apex, so deeply and irregularly sinuated as nearly to obliterate all traces of its original trilobular character (fig. 36).

Much as their beautiful foliated apices differ from that of an expando-ternate spiculum, they are in reality but an extreme development of that form. If we examine them mounted in Canada balsam, with a linear power of about 300, we frequently find at the junction of the shaft with the inner surface of the disc, the remains of three central tubular cavities radiating from the distal termination of the tubular cavity of the shaft, and extending to about the line of its extreme diameter, or rather beyond, as shown in fig. 32, which represents a nearly circular disc or shield; and in the three-lobed forms in which they are apparent, it will be observed that the axial line of each lobe is conformable with one of the three rudimentary tubular cavities radiating from the distal termination of the shaft. There is good reason therefore to believe that these lobes are due to lateral expansions of the radii of originally a ternate form of spiculum. In other cases we find sometimes one, and at other times two of the radiating central cavities bifurcating at their terminations, as in Plate XXIV. fig. 38, which represents the under surface of a fragment of one of these spicula; and in this case the tubular cavities extend considerably beyond the circumference of the distal end of the shaft. This bifurcation of the radiating tubular cavities is in perfect accordance with the corresponding structures in the furcato-patento-ternate spicula of *Pachymatisma Listeri*, Bowerbank, MS., as represented in Plate XXIII. figs. 46 and 47. The number of lobes into which the margin of the great apical disc or shield is divided in the adult condition, is exceedingly various, and, as a matter of course, would be influenced, to a certain extent, by the amount of bifurcation of the radial tubular cavities of the apex; and thus it is probably that we find so great a variation in the form and number of the marginal lobes of these beautiful and interesting spicula.

There is some difficulty in deciding whether this singular form of spiculum should be classed with the connecting ones or with those of the dermis. It is found in a very beautiful but minute siliceous sponge, forming a thin film on the base of a specimen of

Oculina rosea from the South Seas, and it is very little more than the eighth of an inch in diameter, the foliato-peltate apices of the spicula forming a tesselated outer surface to the sponge. Whether the foliated expansions were merely covered by, and attached to the dermal membrane during the life of the animal, or whether they occupied similar situations, and served the same purposes as the expando-ternate spicula of *Geodia* and other similarly constructed sponges, cannot be determined at present, as we have the sponge only in the condition of a skeleton, with but a small portion of the internal animal matter remaining. From the great strength and even disposition of the apical plates over the surface of the sponge, I am inclined to believe that they really form an external defence to the sponge, and have been closely covered by, and connected with, the dermal membrane, and I have therefore provisionally classed them with the spicula of the dermis. The expansion of the terminal radii into continuous plates precludes them from the performance of one of the offices of the ternate spicula in *Geodia* and *Pachymatisma*, that of forming areas for the inner terminations of the intermarginal cells; while their expansion renders them admirable substitutes for the large flat fasciculi that strengthen and support the dermal membranes in *Halichondria panicea*, *incrustans*, and other similar sponges.

Retentive Spicula.

In the interior of the sponge we find a series of retentive organs in the various forms of bihamate and anchorate spicula, which exist in large numbers attached to the surfaces of the interstitial membranes. The simplest forms of spicula of this kind are those of the bihamate, in which we have an acerate form of spiculum, bent near each termination into the shape of a hook, the curves being either in the same plane or at right angles to each other, and the terminations being attenuated and acute.

The next gradation of form is similar to the last, excepting that the terminations, instead of being acute, are more or less solid and clavate. We then find the terminations expanding into circular plates; and again, a fuller and more elaborate expansion is found in the anchorate forms of spicula. The whole of these are attached to the sarcodous membranes of the sponge, in such a manner as to become material aids in the retention of the sarcode with which the membranes are furnished.

As the occurrence of one or more of these descriptions of spicula in a sponge often constitutes an important specific character, it is necessary to describe their peculiarities in detail.

Simple bihamate, are acerate spicula having each end of the spiculum curved in the form of a hook in the same plane and towards each other (Plate XXIV. fig. 39).

Reversed bihamate spicula.—Having each end of the spiculum curved in the form of a hook in the same plane, but in opposite directions to each other (Plate XXIV. fig. 40).

Contort bihamate spicula.—Having each end of the spiculum curved in the form of a hook, but in planes at right angles to each other (Plate XXIV. fig. 41).

ABBREVIATED BIHAMATE.—The bihamate spicula, especially the simple form, are subject to considerable varieties of size and shape. Sometimes, as in abbreviated bihamate, we have the hooks terminating abruptly immediately beyond the proximal curves, as represented in Plate XXIV. fig. 42. I have found but very few specimens of this form, and in no case *in situ*; and I am therefore in doubt whether it be an adult spiculum, or merely a variety arising from an arrest of development.

DEFLECTED BIHAMATE.—When the hami are both deflected in the same direction at nearly right angles to the plane of the shaft (Plate XXIV. fig. 43).

The variety in the amount of curvature at the middle of the shaft of the spiculum is also very great, as represented in Plate XXIV. figs. 39, 42 and 43, but these variations are not purely accidental; on the contrary, they are more or less constant in each species of sponge, and frequently afford good specific characters.

In the simple bihamate form, where the two hami are curved in the same plane and towards each other, the spiculum, in its natural condition, is usually attached to the surface of the membrane by the middle of the back of the curved shaft, and the two hooks are projected into the sarcode at right angles to the plane of the membrane on which it is based. When the hami are developed reversed or at right angles to each other, one of them is then usually imbedded sideways on the membrane, and the other with the shaft is projected from the plane beneath into the sarcode at various degrees of angle. Or in the deflected form the shaft may be firmly cemented to the membrane by one side, while the hami are both projected upward into the mass of sarcode. In some species of sponge one or the other of these forms more especially prevails, but in others, as in *Halichondria incrustans*, JOHNSTON, the simple, reversed, and contort forms are indiscriminately mixed in the tissues, and they occur in every imaginable form of attachment in great profusion, and accompanied by the anchorate forms as well.

The type of this form of spiculum, the simple bihamate, is not peculiar to the Spongiadæ; it occurs in a much more highly organized class, in a radiate animal, *Echinus sphæra*, FORBES, 'British Starfishes,' where we find an abundance of these organs disposed on the external surface of the tubular suckers of the animal, but they are composed of carbonate of lime instead of silex. I am indebted to my friend Mr. JOHN HOWARD STEWART for my knowledge of this interesting fact.

Sometimes the simple forms of bihamate spicula have the middle of the shaft umbonate, and this occurrence is subject to three varieties:—

EXTER-UMBONATE.—When the umbo is on the middle of the outer curve of the shaft (Plate XXIV. fig. 44).

INTER-UMBONATE.—When the umbo is on the middle of the inner curve of the shaft (Plate XXIV. fig. 45).

BI-UMBONATE.—When the middle of both the inner and outer curve of the shaft have an umbo (Plate XXIV. fig. 46).

CLAVATED BIHAMATE.—This singular form of bihamate spiculum was found by Mr. TOPPING in a small piece of sponge from the coast of Sicily, the terminations of the

hami being distended in the form of large round or ovoid masses, as represented in Plate XXIV. figs. 47, 48 and 49. I found the remains of the membranous structures crowded with these very minute spicula, which varied exceedingly in form and in amount of development, and among them were a great variety of other forms of bihamate spicula.

Uniclavate bihamate (Plate XXIV. fig. 47), I believe to be an arrest of development rather than a separate form; for although I found many specimens of it intermixed with the biclavate forms, I also found others assuming transitional forms, that appeared ultimately to connect it with the biclavate spicula.

Biclavate bihamate (Plate XXIV. figs. 48 and 49).—There is a considerable variation in the shape of this spiculum. The form represented by figure 48 is perhaps the most numerous, but that of figure 49 is the largest and most fully developed.

In a new species of British sponge, *Halichondria Hyndmani*, Bowerbank, MS., we find another form of expanded termination to the hami, the pocillated bihamate, which gradually leads us to the true anchorate forms.

In the simple form of pocillated bihamate spicula, the terminations of the curved shaft resolve themselves into two nearly equal, circular, concavo-convex plates, the convex surfaces being in each case outward, and the sides of each plate curving considerably towards the other, their planes being at a right angle to the axis of the shaft. In other cases, one cup will be developed with its plane in the same direction as the axis of the shaft, while the other cup is produced with its plane at right angles to the axis and also of the plane of the first cup. In these variations of development, therefore, this form of spiculum may be compared to the simple and contort forms of bihamate spicula; and in truth they differ from them only in this, that in the one the terminations of the hami are attenuated and acute, and in the other they are expanded into concavo-convex discs.

These two modes of development appear to be subject to a considerable amount of variation in the growth of the terminal discs; as in some cases we find the distal part of the terminal plate to consist of a uniform curve, while in other cases the shaft is carried through the centre of that curve, forming, as it were, a supplemental hook. These variations are in perfect accordance with the general laws of development in this class of spicula, as we find, both in the bihamate and anchorate forms, a considerable amount of difference in the structure and position of these organs in the same species of sponge.

Unipocillated bihamate (Plate XXIV. fig. 50).—One termination fully developed in the form of a cup, while the other is only produced to the extent of the two lateral curves, and a terminal umbo to the shaft.

Simple bipocillated bihamate (Plate XXIV. fig. 51).—Having both terminations developed in the form of cups in coincident planes.

Contort bipocillated bihamate (Plate XXIV. fig. 52).—Two cups being developed, but in planes at right angles to each other.

Umbonated bipocillated bihamate (Plate XXIV. fig. 53).—Having a slight prolongation of the shaft through the distal edge of one or both of the cups; in this case through the distal edge of the lower one only.

Plate XXIV. fig. 54. A view in profile of a unipocillated spiculum: the upper part of the figure represents a side view of the cup, while the termination of the lower portion is more than usually elongated; showing how the umbonation is produced on the distal edge of the spiculum, represented by fig. 53.

The transition from the pocillated bihamate to the more fully developed and beautiful anchorate spicula is easy and natural. The terminations are more elaborately adapted to their retentive purposes; and the mechanism of the curved bow, with the broad palmate terminations of the anchor, which cost man the accumulated experience and wisdom of ages to bring to perfection, is wonderfully foreshadowed in these beautiful little organs.

Anchorate Spicula.

The anchorate spicula, unlike the bihamate forms, appear never to occur reversed or contorted, but always to present their terminations in the same position as those of the bow of an ordinary ship's anchor. In some sponges they are tolerably uniform in shape and proportions, while in others they vary exceedingly, not only while in course of development, but even in their adult condition; they glide so insensibly from one form into another, that it is difficult to draw a distinction between them; and yet, notwithstanding this latitude in shape and development, they are very characteristic of species, as there are always a sufficient number of fully developed ones that exhibit the normal form.

In almost every case of their occurrence, beside the large and fully developed organs, we find a secondary series accompanying them, which are very much smaller in size, and vary exceedingly both in symmetry and amount of development; and there is every appearance that they are simply abortive developments of the larger and more perfect organs, with which they always appear to agree in their normal characters.

There are two primary divisions of these forms of spicula,—equi-anchorate, when both terminations are produced to an equal extent, as in Plate XXIV. fig. 57, or Plate XXV. figs. 1 and 2, and inequi-anchorate, when the distal termination is largely and fully developed, while the proximal one is, comparatively, produced to a very limited extent, as in Plate XXIV. figs. 55 and 56; each of these is subject, to a certain extent, to similar degrees of further diversity of form, which may be designated bidentate, tridentate and palmate. These forms are in truth but different degrees of development of the normal palmate form; but as we find these variations constant in different species of sponges, it is desirable that they should be separately designated, as they afford excellent specific characters. Thus in *Halichondria granulata*, Bowerbank, MS., a new British sponge, we find large equi-anchorate spicula, in which the lateral expansions of each end of the curved shaft or bow which forms the palmate terminations of the spiculum extend along the shaft towards the middle of the bow, very little beyond the point

of curvature forming the basal commencements of the hooks; but although not decurrent on the shaft, the lines of the inner margins are projected forward at an angle of about 45 degrees to the axis of the shaft; and as the outer lines are projected in a corresponding degree, we have the palm produced in the form of two concave conical teeth or palms at each end of the spiculum; and between these there is not the slightest appearance of the ends of the hami, which appear to be equally divided between the terminal palms or teeth. This form I therefore propose to term bidentate equi-anchorate. The same termination occurs among the inequi-anchorate forms; and this mode of the development of the teeth is well shown in the distal or larger portion of the bidentate inequi-anchorate spiculum, represented in Plate XXIV. fig. 55. In other cases the termination of each hook does not thus merge in the teeth, but is carried forward between them either in the form of a simple attenuated termination, as represented in Plate XXIV. fig. 57, or it expands laterally and forms a third intermediate tooth of a hastate form, as represented in Plate XXV. fig. 7. In either of these cases I therefore propose to designate the spiculum as tridentate. In other cases, the lateral expansions forming the palm are continued along the shaft of the spiculum to nearly, or quite, the full extent of the palm, forming a single, undivided, more or less concave termination, as in Plate XXIV. fig. 56. I propose therefore to designate this form as palmato-anchorate; and intermediate forms between the decidedly dentate or palmate ones would be designated as tridentato-palmate (Plate XXV. fig. 7), the palmate form being in excess of the dentate structure; or palmato- tri- or bi-dentate, when the teeth are in the ascendant.

Generally speaking, the ends of the shaft of each anchorate spiculum either become obsolete at the base of the teeth, as in bidentate forms, or they are continued in a regular curve, forming the third tooth, as in the tridentate form; but in some cases, as in *Halichondria plumosa*, JOHNSTON, the shaft appears to terminate abruptly at each end, and the palms or teeth are projected towards each other at a sharp angle to the ends of the shaft or bow of the spiculum: in this case we should term the spiculum angulated anchorate, as represented in Plate XXV. figs. 1, 2 and 3.

The anchorate spicula are not, like the acerate, acuate and other simple forms, of the same shape, or nearly so, from the commencement to the termination of their growth, but, on the contrary, they are developed progressively.

In a new species of *Halichondria*, for which I am indebted to my friend Mr. THOMAS INGALL, the course of their development is displayed in a very interesting and instructive manner. The first condition in which we detect them, is in the form of an exceedingly slender and elongated simple bihamate spiculum, which is readily distinguished from the true bihamate form by the straightness of the shaft, the comparative shortness of the hami, and the obtuseness of their terminations, as represented in Plate XXV. fig. 4. We next find the same form increased in strength, and with slight lateral fimbriæ near each end of the shaft at the commencement of the hami, as in Plate XXV. fig. 5. In a more advanced stage we find a regularly curved extension of the fimbriæ, slightly so

at one extremity of the shaft, and considerably so at the other; and as the development progresses, the curves of the fimbriæ are extended in an outward direction, and become angular; the extremities of the hami expand laterally and assume a foliated appearance, as seen in the distal or larger end especially (Plate XXV. fig. 6); but the fimbriæ at the smallest or proximal end of the spiculum, and the foliated extremity of the adjoining hamus, are still separated from each other; and this progressive development may be observed in all its stages, until the connexion of the parts is completed, and the fully developed form represented in Plate XXV. fig. 7, is produced. The same progressive development of this form of spiculum may be traced in those of *Halichondria lingua*, BOWERBANK, MS., a new species of British sponge from the Hebrides.

In the performance of their natural office in the sponge, we find the same laws of attachment and projection obtain that I have described in treating of the bihamate spicula. In the equi-anchorate forms, where the terminal palms or teeth are equally developed, the shaft is attached by the middle of the external curve; but in the inequi-anchorate forms, where one palm is developed to a very much greater extent than the other, we find the smaller one is attached to the membrane, and the larger is projected at about an angle of 45 degrees. Generally speaking, the anchorate spicula, like the bihamate ones, are irregularly dispersed over the surface of the membranes, but occasionally, as in *Halichondria lingua*, they are developed in circles or rosette-formed groups.

As may be imagined, from their office and situation in a thin stratum of a gelatinoid sarcode, they are at all times small, and in many cases so minute as to require a microscopic power of at least 600 linear to render their structure distinctly visible. They occur in all parts of the sarcodous surface of the interior of the sponge, and are frequently found in greater profusion than usual on the inner or sarcodous surface of the dermal membrane; but I do not recollect an instance of their occurrence on the outer surface of that organ, while on the sarcodous or interstitial membranes they are frequently to be observed in about equal proportions on both sides of the same membrane.

It will not be necessary to describe or figure the whole of these variable forms of spicula. I have therefore selected those only that may be considered more especially as type forms.

TRIDENTATE EQUI-ANCHORATE (Plate XXIV. fig. 57).—Having each termination equally and fully developed, in the form of two lateral and slightly palmate, and one central attenuated tooth. From an undescribed sponge in the collection of Mr. GEORGE SHADBOLT: ×660.

BIDENTATE INEQUI-ANCHORATE (Plate XXIV. fig. 55).—Each termination divided into two distinct teeth, the distal ones being largely and fully developed, while the proximal ones are but slightly produced. From an undescribed sponge from the coast of Sicily: ×660.

PALMATED INEQUI-ANCHORATE (Plate XXIV. fig. 56).—Having the distal termination largely developed in the form of a cordate palm, while the proximal end is produced to

a much less extent, is compressed laterally, and has the terminal point expanded into a short broad tooth.

DENTATO-PALMATE INEQUI-ANCHORATE (Plate XXIV. fig. 58).—Having the distal spatulate palm produced to the extent of about half the length of the spiculum, while the proximal one is developed in the same form to only about one-fourth the length of the spiculum, and having the apices of the hami produced beyond the extremities of the palms, each in the form of a short obtuse tooth. From *Spongia lobata*, MONTAGU, in the collection of Professor GRANT: ×1060.

DENTATO-PALMATE ANGULATED ANCHORATE (Plate XXV. figs. 1, 2, 3).—I have found this form of spiculum only in *Spongia plumosa*, MONTAGU. Each of the hami appear as if forcibly compressed towards the termination of the shaft, which seems to have been equally influenced by the compression, so that the hami have become angulated, as represented in the profile view of one of the spicula (Plate XXV. fig. 3). The whole of the spicula are dentato-palmate, and the adult ones have the terminations of the hami strongly produced, as represented in Plate XXV. fig. 1; while in the immature spicula, although the palms are fully produced, the tooth appears in a rudimentary condition, as in Plate XXV. fig. 2.

Spicula of the Sarcode.

As the tension spicula of the membranes are destined to strengthen and support those tissues, so the numerous and beautiful tribe of stellate spicula appear to be devoted to connect and give substance to the gelatinoid sarcode, which so abundantly covers the whole of the interior membranous structures of the sponges in which they occur. It is difficult at first sight to determine the difference in the office of this class of spicula and those of the internal retentive ones; and it is probable that in some cases, when it so happens that the radii of the stellate forms rest on, and become cemented to the membranous structures, they may perform, to a certain extent, the same function, that of assisting to connect the membranes and sarcodous structures more firmly together. But generally speaking this is not the case, and especially with the smaller forms of these organs; for in comparatively thick layers of sarcode we find them in all parts, and manifestly unconnected with the membranes beneath; and in sponges which have undergone such an amount of decomposition as to leave the membranous structures entirely or very nearly free from sarcode, while we see the retentive forms remaining firmly attached to the membranes, we rarely find the stellate ones, excepting when entangled among the surrounding spicula of the skeleton. We may therefore reasonably conclude, that their normal function is that of increasing the strength and substance of the sarcodous structure of the sponge.

In the performance of this office of strengthening and supporting the sarcode, we find a singular class of spicula, consisting of from three to six rays, emanating from a common centre, and always disposed at right angles to each other. Between the extreme forms of development of these and the simple stellate spicula, there is a very great amount of structural difference; but on a more intimate acquaintance with the intermediate

forms, we find them passing into each other so gradually as finally to connect the whole into one group.

Simple Stellate Spicula.

Stellate spicula are composed of few or many radii emanating from a centre in all directions. Their simplest form is when the bases of the radii all proceed from a common central point (Plate XXV. fig. 9), in which case they should be designated simply stellate spicula; but when the radii spring separately and distinctly from a common central spherical or oval base, they should be designated sphero-stellate spicula (Plate XXV. figs. 13, 16, 17). In both these classes of spicula there is a very considerable difference in their size and form, in the various species of sponges in which they occur.

ATTENUATO-STELLATE (Plate XXV. fig. 9).—Having the radii gradually attenuated from the base to the apex.

Pachymatisma Johnstonia, BOWERBANK, affords a large and very excellent type of this form of spiculum. The radii vary from three to seven or eight, but five or six rays are the most common numbers. *Geodia gibberosa*, the type species of LAMARCK's genus, also affords an excellent example of this form of spiculum.

CYLINDRO-STELLATE (Plate XXV. fig. 10).—Having the radii of equal diameter throughout and terminating hemispherically: from *Pachymatisma Johnstonia*, BOWERBANK.

This form also occurs abundantly in *Tethea robusta*, BOWERBANK, MS. The sponge is in the British Museum, and was brought from Australia by Mr. S. STUTCHBURY. The form and proportions of these spicula vary considerably; sometimes the distal terminations of the radii are slightly inclined to be clavate, and at others there is a gradual transition from simply stellate to subsphero-stellate. The radii are also in some of the larger specimens slightly inclined to attenuation.

CRASSATO-CYLINDRO-STELLATE (Plate XXV. fig. 11).—This spiculum is remarkable from its having the radii twice as broad as they are thick, and their distal terminations abruptly truncated. It occurs intermixed with the more regular forms of cylindro-stellate in *Tethea robusta*.

CLAVATED SUBSPHERO-STELLATE (Plate XXV. fig. 12).—The cylindrical radii having the distal terminations more or less dilated, and the central basal sphere not exceeding in diameter the length of one of the radii. This form of spiculum is very abundant in *Tethea Ingalli*, BOWERBANK, MS., intermingled with attenuato-cylindro-stellate spicula.

CLAVATED SPHERO-STELLATE (Plate XXV. fig. 13).—The cylindrical radii having the distal terminations dilated, and the central basal sphere greater in its diameter than the length of one of the rays. This spiculum is abundant in the sarcode of the dermal and interstitial membranes of *Geodia Barretti*, BOWERBANK, MS. It is very minute, the extreme diameter varying from $\frac{1}{5000}$th to $\frac{1}{7000}$th of an inch.

SUBSPHERO-STELLATE (Plate XXV. fig. 14).—Having the radii more or less acutely conical, and as long or longer than the diameter of the central basal sphere: from

Tethea Ingalli, Bowerbank, MS. In this sponge and in other species this form occasionally presents a very gradual transition from the purely stellate form to the full subsphero-stellate one, in which the radii and the spherical centre are of about equal length, while in the fully developed sphero-stellate forms this graduation is never seen.

Sphero-stellate (Plate XXV. fig. 15).—Having the radii acutely conical and based on a large central sphere of greater diameter than the length of the radii. *Tethea robusta*, Bowerbank, MS., a new species from Australia, in the British Museum, presents an excellent type of this form of spiculum. As the central nucleus appears, under favourable circumstances, we distinctly trace a central canal in each ray, passing from the centre of the sphere to near the distal termination of each of the radii, as represented in Plate XXV. fig. 17. These canals are not usually apparent in the perfect spicula, probably in consequence of the fluid being hermetically sealed within the canals of the radii, but I could not determine the presence of the fluid by polarized light.

Sphero-stellate with cylindro-subfoliate radii (Plate XXV. fig. 16).—Having the cylindrical radii slightly expanded and somewhat foliated at the distal extremities. This remarkable form was obtained by washing some specimens of *Oculina rosea*, from the South Sea, and there is little doubt of its being from an unknown species of *Tethea*.

Elongo-attenuato-stellate (Plate XXV. fig. 18).—Having the radii springing from an elongated instead of a central base. This form of spiculum occurs abundantly in *Tethea muricata*, Bowerbank, MS.: from Vigten Island, Norway.

Arborescent elongo-subsphero-stellate (Plate XXV. fig. 19).—Having the radii springing from a dilated and elongated common base of about the dimensions of two subsphero-stellate spicula, partially fused together.

This remarkable form occurs abundantly in *Geodia carinata*, Bowerbank, MS., from the South Sea. The nucleus, whence the radii proceed, is always more or less elongated, but is not usually so much dilated as in the specimen figured. The arborescent character of the distal terminations of the radii is also very variable.

Pileated cylindro-stellate (Plate XXV. figs. 20, 21, 22 and 23).—Having several recurved spines uniting and forming a pileus at the apex of the ray, shaped like that of a young mushroom. These singularly variable spicula are abundant in *Spongilla plumosa*, Carter. They are remarkable as affording a series of transitional forms from a single straight spiculum to the regular multiradiate stellate one. Fig. 20 represents, about the first stage of variation from the simple elongate spinous spiculum, a few rather strongly produced cylindrical spines appearing near the middle of the shaft. In fig. 21 two of these spines are considerably more elongated than those in fig. 20, and the shaft is not so long as that of fig. 20. In fig. 22 the axial shaft is still more curtailed in its proportions, and the central radii are further elongated and increased in number; and in fig. 23 we find the axial spiculum scarcely distinguishable from the lateral rays. When the radii projected are few in number, they are usually at right angles to the axial spiculum; but when they are produced in greater numbers, they are projected at various

angles, and the axial spiculum can scarcely be detected. In spicula having numerous radii, they frequently unite at their bases, and produce their extreme variation of form, a subsphero-stellate spiculum. No two of these singular spicula are alike, and they present every imaginable variation in the mode of their development. In their origin from an axial spiculum, and in their tendency to the projection of secondary radii at right angles to that axis, these spicula form a connecting link between the simple multiradiate forms and the more complicated ones belonging to the next division of the subject.

Compound Stellate Spicula.

The curious and beautiful forms of this series of spicula all belong to the class of sponges that have a skeleton composed of siliceous fibre, and they are principally from tropical climates. The central basal structure from which the radii are projected, in every case with which I am acquainted, is a rectangulated hexradiate spiculum, from the apices of which a variety of beautiful terminations are projected, which vary in form exceedingly in different species of sponges. In the class of sponges to which I have alluded there are also numerous rectangulated spicula, varying in the number of radii from three to six, the apices of the radii being either acutely terminated or more or less clavated, and these forms vary very much in size. They are unconnected with the skeleton, and evidently belong to the Sarcodous system of the sponge. They are very much larger than the hexradiate centres of the compound stellate spicula, but as they are evidently the normal forms of that tribe, I shall describe the general characters of these large, simple, hexradiate forms before those of the more complicated stellate ones.

Attenuated rectangulated hexradiate (Plate XXV. fig. 32).—The first state in which we find them is in that of an inequi-acerate spiculum (Plate XXV. fig. 24), in which condition they are in fact the two axial radii of the hexradiate form which they ultimately attain when in their fullest state of development. In the next stage we find a bud-like projection issuing from the side of the thickest portion of the inequi-acerate spiculum (fig. 25), which is ultimately developed in the form of a rectangulated triradiate spiculum, as in fig. 28. Or two buds are simultaneously projected, as in figs. 26 and 27, and the result is a regular rectangulated quadriradiate form, as in fig 30. Or if the second ray be at a right angle to the one first projected, the result is an irregular quadriradiate figure, as represented by fig. 29. In like manner the irregular pentradiate form arises from the absence of one of the four secondary rays, as in fig. 31; or it sometimes occurs that the apical portion of the inequi-acerate axial spiculum is deficient, and then the result is, as represented by fig. 33, a regular pentradiate form. If the whole of the radii are equally produced, the result is then the regular attenuated rectangulated hexradiate spiculum, fig. 32.

Sometimes, but rarely, we find a single ray more or less spinous at its distal end; in this case it is probable that it was attached by that point to the membranous structure, or to some part of the keratode of the skeleton.

The whole of these interesting spicula were obtained from Mr. Cuming's specimen of

Euplectella aspergillum. They are abundant in that sponge, frequently filling up the interstices of the network of the siliceous skeleton, or otherwise entangled in the tissues. In Dr. A. FARRE's specimen of *Euplectella* they are equally abundant, and are not to be distinguished from those in Mr. CUMING's specimen. They are, like the great external prehensile spicula, and the fibre of the skeleton, composed of numerous concentric layers of silex, which readily separate from each other by decomposition.

I cannot say with absolute certainty that this tribe of spicula belong really to the sarcode, as I have never seen specimens of either of the species I have named, in which they occur in profusion, in such a state of preservation as to allow of their position being positively determined; but as in another specimen of sponge with a siliceous skeleton like that of *Dactylocalyx pumicea*, STUTCHBURY, the sarcode is preserved in excellent condition, and occurs in such abundance, filling all the interstices of the skeleton of the sponge, and affording ample space for the imbedment of such spicula in its substance, I am, therefore, induced to think it probable that a similar abundance of sarcode may exist in *Dactylocalyx* and other similarly constituted sponges, and that hereafter even the largest of this tribe of spicula will be found completely imbedded in the sarcode.

SLENDER ATTENUATED RECTANGULATED HEXRADIATE (Plate XXV. fig. 34).—Beside the large and stout attenuato-hexradiate spicula in *Euplectella aspergillum*, there are comparatively small and very slender ones, many of which are nearly of the same proportions as the larger ones; but generally speaking the axial radii are more elongated, and in some cases the basal end is extended to four or six times the length of the apical portion.

These spicula do not present the same irregularity in their development that we observe in the stout ones, and it is a rare occurrence to find one without the full number of rays. They are exceedingly numerous in the sponge, and they occur in closely packed fasciculi, the axes of the spicula nearly touching each other. Amidst these fasciculi we find the large stout forms imbedded, the whole of them apparently having been completely enveloped by the sarcode of the sponge.

CYLINDRO-RECTANGULATED HEXRADIATE: APICALLY SPINED (Plate XXV. fig. 35).—This form is very abundant in an undescribed species of *Euplectella* in the Museum of the Jardin des Plantes, Paris. The figure represents the upper portion of the spiculum only, the lower portion of the axial shaft being exceedingly elongated. When examined with a power of 400 linear, the apices of the radii are seen to be abundantly, but minutely spined. The axial shaft of this spiculum without any of the lateral radii developed, is also abundant; it is exceedingly long, and at the proper distance below the apex we often observe a gradual enlargement of the diameter, as represented in fig. 37, and the rudimentary canals for the lateral radii are frequently apparent.

This form of spiculum is also very abundant in *Dactylocalyx pumicea*, STUTCHBURY, *Iphiteon* of the French Museum. In general character they are very similar to those of the *Euplectella* described above, with the addition of the apices of the radii being more or less clavated.

All the simple rectangulated hexradiate forms of spicula hitherto described are large, compared with the rectangulated hexradiate spicula which form the central bases of the compound stellate forms, and excepting the disparity in size, the transition from the last form described, to the complicated and beautiful compound stellate ones, is easy and natural; the apices of the hexradiate form becoming the bases of the numerous radii of the stellate ones. This transition from the simple to the compound forms is admirably illustrated in a bifurcated spiculum that occurs in the new species of *Euplectella* in the Museum of the Jardin des Plantes, which I propose to designate as follows:—

BIFURCATED RECTANGULATED HEXRADIATE STELLATE (Plate XXV. fig. 38).—It is minute and slender, and the bifurcating rays are irregular, often tortuous, and are frequently not produced on one or two of the primary radii. These indecisive characters, common to all the specimens of this form of spiculum that I have seen, combined with the elongate characters of the radii, seem strongly to mark this spiculum as the connecting link between the simple hexradiate and the compound stellate forms of spicula.

TRIFURCATO-HEXRADIATE STELLATE (Plate XXV. fig. 39).—The central radii consist of six rectangulated primary rays of equal length, each of which terminates in three equidistant secondary attenuating rays, which are projected from the apices of the primary ones at an angle of about 45 degrees to the common basal, or primary ray.

These spicula occur in abundance in *Euplectella aspergillum*, OWEN, and in *Dactylocalyx pumicea*, STUTCHBURY. I observed them first in some fragments of the magnificent specimen of *D. pumicea*, half of which is in the possession of Dr. J. E. GRAY; and the other half is, I believe, in the Museum of the Bristol Institution; and subsequently in a second specimen in the possession of my friend Mr. THOMAS INGALL, in whose sponge there are remains of the sarcodous structure, which is literally crowded with them and the spinulo-hexradiate stellate ones. They are also abundant in a specimen of, I believe, a different species in the Museum of the Jardin des Plantes at Paris, where the sponge is designated *Iphiteon*. There is a slight difference in the form and mode of radiation of the secondary rays in the specimens of these spicula that occur in Mr. CUMING's beautiful specimen of *Euplectella aspergillum* and those from *Dactylocalyx*, and they are not in the former species accompanied by the spinulo-hexradiate ones, as in *Dactylocalyx pumicea*. In my friend Dr. A. FARRE's beautiful specimen of *Euplectella* they are to be found, but not so abundantly as in Mr. CUMING's sponge, but they are of precisely the same form as the spicula from that specimen.

SPINULO-TRIFURCATED HEXRADIATE STELLATE (Plate XXVI. fig. 1).—The central radii consist of six rectangular primary rays of equal length, each of which terminates in three equidistant cylindro-spinulate radii, projected from the apices of the primary ones at an angle of about 45 degrees to the axis of the common basal primary ray.

Occasionally we find four secondary radii in place of three, but this is not of common occurrence; and in the fully developed spicula the spinulate terminations are usually not globular, but of a more or less depressed form. This spiculum I have found only in

Dactylocalyx pumicea, intermingled with the trifurcato-attenuato-hexradiate spicula, and it appears to be even more abundant than the last-named form.

SPINULO-QUADRIFURCATE HEXRADIATE STELLATE (Plate XXVI. fig. 2.).—A rectangulated hexradiate spiculum, having each primary ray terminating in four nearly equidistant cylindro-spinulate secondary radii.

These spicula occur abundantly in a beautiful and unique specimen of a cup-shaped siliceo-fibrous sponge in the cabinet of my friend Mr. THOMAS INGALL. The remains of the sarcode are crowded with them in a perfect state of preservation. The specimen represented by figure 2 has had three of its primary radii broken off near their common base, thus enabling us to see distinctly the structure of this curious and beautiful form of spiculum.

FLORICOMO-HEXRADIATE (Plate XXVI. figs. 3 and 4).—The central radii consist of six rectangulated primary rays of equal length, with slightly expanded terminations, from each of which there issue seven or more petaloid secondary spicula, the whole forming one of the most beautiful simulations of a flower imaginable.

Each petaloid spiculum is slender at its proximal termination, and continues to be so until near its distal end, where it expands laterally, and presents a nearly semicircular concavo-convex termination, with a beautiful dentate margin, the number of the dents being usually seven. Each of the petaloid spicula curves gently outward from its base, the flowing line returning towards the central axis of the flower at about half of its height from the base, and then it again curves outward, until the apical expansion is at right angles to the floral axis; so that the whole resolves itself into a form like that of the flower of a Jasmin. The beautiful terminal petaloid expansions, with their regularly disposed marginal dents, renders the illusion complete; the united basal curves looking as if they had been produced by the swelling ovarium of a flower.

I have obtained a considerable number of these elegant spicula from my friend Mr. CUMING's beautiful specimen of *Euplectella aspergillum*, which, with his accustomed liberality, he placed at my disposal for examination. They are found also in Dr. A. FARRE's specimen of *Euplectella*, agreeing in every respect with those from Mr. CUMING's sponge.

CORONATO-HEXRADIATE STELLATE (Plate XXVI. fig. 5).—The central radii consist of six rectangulated primary rays of equal length, each terminating in a discoid expansion, the margin of which is furnished with numerous curved petaloid radii.

I obtained this beautiful but very minute spiculum through the kindness of Professors MILNE-EDWARDS and VALENCIENNES, from a specimen of *Euplectella* in the Museum of the Jardin des Plantes, Paris, in which there are two of these beautiful sponges, one being in a much better state of preservation than the other, and in the mutilated specimen this beautiful form was found.

The spiculum is evidently not in a perfect state of preservation, as there are only four rays out of the six present; but at the centre of the spiculum there is the indication of the former existence of one of the two missing radii. The coronal terminations are very

like the receptacle of the great common Helianthus or Sun-flower, and the marginal radii resemble the petals of the same flower, but are somewhat longer in their proportions. The spiculum is very minute, the extreme diameter measuring $\frac{1}{1138}$ of an inch, and the diameter of the largest coronal termination $\frac{1}{3571}$ of an inch.

POCILLATED HEXRADIATE STELLATE (Plate XXVI. fig. 6).—The central radii consist of six rectangulated primary rays of equal length, each terminating in a concavo-convex disc or cup, the convex surface being outward.

I found this extremely minute form entangled in the tissues of a specimen of *Halichondria incrustans*, dredged up by my friend Mr. M'ANDREW at the Orkney Islands, and it is probably from one of the small species of *Euplectella* that are found in the North Sea.

The specimen has shifted in the slide in which it is mounted into so oblique a position, that the accuracy of the size only can be depended upon. But when first observed, immediately after it was mounted, I obtained a very satisfactory view of its structure, and made a rough sketch of it at the time, and from this and from its projection by the camera lucida at the present period, the drawing of it has been made. There are four only of the radii remaining, and its hexradiate form is therefore only surmised on the strength of its affinity to more perfect specimens of that type of form. It is the most minute spiculum of this description that I have seen; the extreme diameter of the distal ends of the opposite radii measured only $\frac{1}{3143}$ of an inch.

Beside the stellate and hexradiate forms of spicula, there are a few others found in the sarcode which do not appear to be constructively connected with either of those groups.

ATTENUATO-RECTANGULATED TRIRADIATE: APICALLY SPINED (Plate XXVI. fig. 7).—This form is not, as it might be hastily surmised, the triradiate stage of development of a hexradiate spiculum. It is larger in every respect than the slender variety of the hexradiate form, and less stout, but much longer than the stout variety of the hexradiate form previously described; and although intermingled with them and the other forms of spicula in *Euplectella aspergillum*, it is always readily to be distinguished by an experienced observer.

The spines are small but thickly dispersed over the apices of the radii for a short way down the shaft, and occasionally the apices of the radii are more or less clavate.

CYLINDRO-RECTANGULATED TRIRADIATE.—This form of spiculum is abundant in *Dactylocalyx pumicea*, STUTCHBURY. The basal axial ray is often very much elongated. The radii are also incipiently spined, and their apices are more or less spinulate or clavate. The form of this spiculum is precisely that of fig. 7, Plate XXVI., excepting that the radii are cylindrical instead of attenuated.

SPICULATED BITERNATE (Plate XXVI. figs. 8 and 9).—I found several of these spicula in the dust shaken from the siliceo-fibrous massive sponge at the base of my friend Dr. A. FARRE'S specimen of *Euplectella cucumer*, OWEN, and I have no doubt of their belonging to the sarcode of the sponge at its base. They appear to vary greatly in the amount of their development. In figure 8 the biternate spicula are simple, and it is

spiculated at one end only. Some of them were similar to figure 8, but were spiculated at both ends; while in others, one or more of the rays have their terminations bifurcated as in figure 9, which represents a spiculum with the greatest number of bifurcated radii that I have yet seen. They vary also considerably in size; the simpler of the two forms, figure 8, being much larger than that represented by figure 9.

MULTIANGULATED CYLINDRICAL (Plate XXVI. fig. 10).—This singular little form of spiculum occurs abundantly in the sarcode of *Geodia carinata*, BOWERBANK, MS. It is angulated alternately in opposite directions, at regular distances, from two to six or seven times. It is extremely minute; a full-sized five-angled one measuring in length $\frac{1}{1304}$th of an inch, and diameter of shaft $\frac{1}{16000}$th of an inch. It is difficult to decide whether this should not be considered as belonging to the membranes; but its extreme minuteness is not in favour of that supposition, and in carefully focusing the specimens of the spicula *in situ*, no two appear to be imbedded in the same plane above the interstitial membranes, where they are to be observed best. I have therefore considered it as belonging to the sarcodous rather than to the membranous structures*.

Spicula of the Gemmules.

The spicula appropriated to the gemmules of sponges occur in various modes of disposition.

1st. They are imbedded irregularly in an external envelope of the gemmule, or on the surface of the gemmule itself, at right angles to lines radiating from its centre.

2ndly. They are arranged symmetrically in the crust of the gemmule parallel to lines radiating from its centre.

3rdly. They are disposed in fasciculi in the substance of the gemmule, from the centre to the circumference.

In the first mode of disposition they are sometimes of the same form as those of the skeleton, but considerably less both in length and diameter, to adapt them to the office they have to perform. In other cases they differ materially in both size and form from those of the surrounding skeleton; but in every case with which I am acquainted, their long axes are parallel to the outer surface of the case of the gemmule, or to the surface of the gemmule itself.

In the second mode of disposition they are immersed in the comparatively thick crust of the gemmule, their long axes being always at right angles to lines radiating from its centre to its circumference. Their forms become widely different from those of the skeleton spicula, and especially adapted to their peculiar office; and their terminations frequently expand into broad plates, as in *Spongilla fluviatilis*, JOHNSTON. Their forms vary considerably in shape and structure in different species. In the gemmules of some sponges, one of these modes of the disposition of their spicula only can be observed.

* Since the above description was written, I have found in a sponge from the Mauritius specimens of this form of spiculum, both simple and strongly spinous, with seven angulations, and very much larger and longer than the one figured.

Thus in *Spongilla lacustris*, JOHNSTON, we find the elongate form of spicula, and in *Spongilla fluviatilis*, JOHNSTON, the birotulate form; while in *Spongilla gregaria*, BOWERBANK, MS., we find both; the first occurring on the outer surface of the coat of the gemmule, and the second immersed in the crust at its inner surface.

In the third mode of arrangement, where the spicula abound in every part of the gemmule, as in *Tethea cranium*, JOHNSTON, they are various in form, but resemble to a considerable extent those of the skeleton, with an intermixture of forms peculiar to the gemmule. I shall therefore describe these organs in the order in which I have enumerated their modes of occurrence.

1st. SPICULA ELONGATE, DISPOSED AT RIGHT ANGLES TO LINES RADIATING FROM THE CENTRE OF THE GEMMULE TO ITS SURFACE.

ACERATE (Plate XXVI. figs. 11 and 12).—This form occurs abundantly in the envelope of the gemmule of *Spongilla Carteri*, BOWERBANK, MS., or *Sp. friabilis*, CARTER, from the water-tanks of Bombay; and in *Sp. Brownii*, BOWERBANK, MS., from the River Amazon. In both these species the spicula of the gemmules agree in form with those of their respective skeletons, but are not more than half their size. Fig. 11, a spiculum of the envelope of the gemmule of *Spongilla Carteri*. Fig. 12, a spiculum of the envelope of the gemmule of *Spongilla Brownii*.

SUBARCUATE ACERATE: ENTIRELY SPINED (Plate XXVI. fig. 13).—The envelope of the gemmule of *Spongilla lacustris*, JOHNSTON, abounds in this form. The length and mode of spination of these spicula are nearly the same in all of them, but the amount of curvature varies from nearly straight to nearly a semicircle, as represented by fig. 13; and in one case the terminations of the spiculum have crossed each other, forming a loop. In some sponges the spicula of the gemmules agree in form with those of the dermal membrane, but this is not the case in the present instance, those of the membrane being slender fusiformi-acerate.

FUSIFORMI-ACERATE: ENTIRELY SPINED, SPINES CYLINDRICAL (Plate XXVI. fig. 14).—These spicula are long, slender, and very slightly curved; they are dispersed abundantly in the envelope of the gemmule of *Spongilla Batei*, BOWERBANK, MS., from the River Amazon.

The spination of the spiculum is very remarkable; those near the middle of the shaft are frequently of a length equal to half or two-thirds the greatest diameter of the spiculum on which they are based. They are of the same diameter from the base to the apex, and terminate as abruptly as if they had been truncated.

ACERATE: ENTIRELY SPINED, SPINES CONICAL (Plate XXVI. fig. 15).—This form of spiculum occurs in the envelope of the gemmule of *Spongilla cinerea*, CARTER. It is very abundant and somewhat minute, and requires a linear power of about 600 to define it accurately. The spines are very numerous, and all of them appear to pass from the spiculum at right angles to its axis. The largest of them is about one-third the length of the greatest diameter of the spiculum.

CYLINDRICAL: INCIPIENTLY SPINED (Plate XXVI. fig. 16). This short stout form of spiculum occurs abundantly in the envelope of *Spongilla gregaria*, BOWERBANK, MS., from the River Amazon. It is usually without spines, but occasionally a few incipient ones are dispersed over the shaft.

CYLINDRICAL: ENTIRELY AND RECURVEDLY SPINOUS (Plate XXVI. fig. 17).—This large and beautiful form of spiculum is abundant in the envelope of the gemmule of *Spongilla alba*, CARTER. It has a considerable amount of curvature, and the spination is remarkably bold and striking. Very few of the spines issue from the shaft at right angles to its axis, and these are always near its middle; the remainder of the spines are all curved from the apices of the spiculum towards the middle of the shaft. The spines are congregated in considerable numbers at each termination of the spiculum, and are larger and more curved there than on any other part of the shaft.

CYLINDRICAL: ENTIRELY SPINED; SPINES OF THE MIDDLE CYLINDRICAL, THOSE OF THE TERMINATIONS CONICAL AND RECURVED.—These spicula might readily be mistaken by a hasty observer for those of *Spongilla alba*, but a closer observation exhibits essential differences in their mode of spination. The spines are distributed over the whole of the spiculum, and are rather more numerous at the terminations than towards the middle of the shaft. At the ends of the spiculum the spines are conical, acutely terminated, and are recurved towards the middle of the shaft; but near the middle of the spiculum the spines are cylindrical, stout, obtusely terminated, and occasionally expanded or branched. They are very numerous in the envelope of the gemmule of *Spongilla cinerea*, CARTER, from the water-tanks of Bombay. They are so nearly of the same form as those represented in Plate XXIV. fig. 17, as to render it unnecessary to figure them.

2nd. SPICULA DISPOSED IN LINES RADIATING FROM THE CENTRE TO THE CIRCUMFERENCE OF THE GEMMULE.

Birotulate and Boletiform Spicula.

The whole of this beautiful group of spicula occur in the thick coriaceous proper coat of the gemmules of the Spongilladæ. Sometimes we have but one form thus located, as in *Spongilla fluviatilis*, JOHNSTON, where we find them very close together in the case of the gemmule, the outer rotula supporting the external membrane, and the inner one performing the same office for the internal one. At other times we find two distinct forms in the coat of the gemmule, as in *Spongilla recurvata*, BOWERBANK, MS., from the River Amazon; the inner one being slender boletiform, and the outer one multihamate birotulate. In every case these spicula are so completely immersed in the thick coriaceous coat of the gemmule, that they are perfectly invisible under ordinary circumstances; and it is only after the gemmule has been boiled in nitric acid for a very short period, that it is rendered sufficiently transparent to allow of the spicula being seen *in situ*.

The progressive development of these forms of spicula is very beautifully exhibited in the spicula from the gemmules of *Spongilla plumosa*, CARTER. We first observe them,

with a linear power of 660, in the shape of slender, smooth, cylindrical spicula, with a slight enlargement at each termination, and without the slightest indication of spines on the shaft; and in this condition the central cavity is large, occupying about one-third of its diameter (Plate XXVI. fig. 18). In the second stage, the only alteration in its form is an enlargement of the terminations, the edges assuming an angular shape, and a few slender spines are observable (Plate XXVI. fig. 19). In the third stage of development the terminations assume the form of distinct circular plates or incipient rotulæ, the margins of which are slightly crenate; the shaft exhibits numerous long slender spines, and the central cavity now does not occupy more than one-fifth of the diameter of the spiculum (Plate XXVI. fig. 20). From this form specimens in every stage of development may be readily traced, until the strongly spinous margin, the prominent convexity of the rotulæ, and the robust shaft with its long conical spines, indicate the completely adult condition of the spiculum, and in this state the central cavity can very rarely be seen (Plate XXVI. fig. 21).

The growth of these spicula in their early stages is probably very rapid, as the number of those in the first and second stages is remarkably small as compared with those in the third and subsequent stages.

In the inequi-birotulate spicula of *Spongilla paulula*, Bowerbank, MS., we find a number of radial canals passing from each end of the central cavity of the shaft to the extreme circumference of the rotulæ; and it is therefore probable that this expanded part of the spiculum is similar in character to that of the folio-peltate spiculum which I have described page 299, in treating of the spicula of the membranes; and that they are, in fact, originally composed of a series of terminal radial spicula expanding and coalescing laterally, and thus forming one plane circular surface in place of numerous separate radii (Plate XXVI. fig. 32).

Birotulate: margins of the rotulæ entire (Plate XXVI. figs 23, 24, 25 and 26). —This form of spiculum occurs in the coat of the gemmule of *Spongilla gregaria*, Bowerbank, MS., from the River Amazon. The rotulæ consist of two thin flat plates of equal size, without any appearance of crenation at their margins. They are connected by a very short thick smooth cylindrical shaft, a slight protrusion of which through the centre of each rotula forms a very short convex umbo on the centre of each outer surface. They are very minute; an average-sized one measured, length, $\frac{1}{3000}$th of an inch; diameter of rotula, $\frac{1}{1538}$th of an inch; length of shaft within the rotulæ, $\frac{1}{6538}$th of an inch.

Birotulate: rotulæ irregularly and deeply dentate (Plate XXVI. figs. 27 and 28). —This form of spiculum is abundant in the coat of the gemmule of *Spongilla fluviatilis*, Johnston. The rotulæ are flat and are deeply and irregularly divided, the divisions frequently extending from the circumference to very near the centre. The smallest diameter of the shaft is usually at its middle, from which part it gradually increases in size as it approaches the rotulæ. Occasionally, but rarely, we find a single large spine projected from the shaft at right angles to its axis.

BIROTULATE: ROTULÆ IRREGULARLY AND DEEPLY DENTATE, SHAFT MEDIALLY SPINED (Plate XXVI. fig. 29).—This form occurs in the gemmules of *Spongilla Meyeni*, CARTER, from the water-tanks of Bombay. It is the largest spiculum of that form that I have yet seen. It differs from the congenerous form in *Spongilla fluviatilis*, inasmuch as the spination of the shaft in *Sp. Meyeni* is the rule, while in *Sp. fluviatilis* it is a rare exception.

RECURVO-DENTATE BIROTULATE (Plate XXVI. figs. 21 and 22).—This elegant form of spiculum is from the coat of the gemmule of *Spongilla plumosa*, CARTER, from the water-tanks of Bombay. It is the most perfectly developed form of its class with which we are acquainted. It varies to some extent in size and form. The length of the shaft is from three to three-and-a-half times the diameter of the rotulæ, and it is covered profusely with stout acutely-conical spines, which frequently exceed the diameter of the shaft in length.

The rotulæ are internally concave, and considerably and regularly convex on the outer surface, and they have their margins irregularly dentate, the dents in fully-developed specimens being much recurved. The shaft is usually regularly cylindrical throughout its length, but in very fully-developed spicula it sometimes increases considerably in its diameter at a slight distance from its junctions with the rotulæ.

In this spiculum, as it occurs in *Spongilla plumosa*, CARTER, the gradual development of the birotulate form is beautifully displayed, as I have described at length in my introductory observations, page 316: figs. 18, 19 and 20 exhibit progressive stages of development.

MULTIHAMATE BIROTULATE (Plate XXVI. fig. 30).—This singular form of spiculum is from the outer portion of the gemmules of a new species of freshwater sponge from the River Amazon, *Spongilla recurvata*, BOWERBANK, MS.

The external surfaces of the rotulæ are smooth, very convex, and in many cases almost hemispherical; so that the points of the curved spines are in the direction of lines parallel to the shaft of the spiculum, and the rotulæ are cleft almost to the point of union with the shaft. The number of the curved spines vary; in one rotula there were as many as ten, but the usual number is five or six. An average-sized specimen measured $\frac{1}{1050}$th of an inch long; diameter of the rotulæ, $\frac{1}{1500}$th of an inch; and diameter of the shaft, $\frac{1}{4000}$th of an inch.

INEQUI-BIROTULATE (Plate XXVI. figs. 31 and 32).—This spiculum exhibits a gradual transition from the fully developed birotulate to the completely boletiform tribe of spicula. It occurs in a new species of freshwater sponge, *Spongilla paulula*, BOWERBANK, MS., from the River Amazon. It is a stout fully developed form, and the whole of them exhibited, as nearly as possible, the same proportions, which are as follows:—

Length $\frac{1}{750}$th of an inch, diameter of largest rotula $\frac{1}{1818}$th of an inch, and diameter of the shaft at the middle $\frac{1}{6000}$th of an inch. The shaft increases slightly and gradually in its diameter from the middle to each of the rotulæ. The central cavity of the shaft is very distinct, and has a diameter equal to about one-fifth that of the medial one of the

shaft. From both terminations of the shaft a number of minute radial canals pass from the centre to the circumference of the rotulæ, and in one of the large ones I counted twenty radial canals. The rotulæ are flat, or very slightly convex outward near the centre, and the margins are perfectly entire.

Boletiform (Plate XXVI. fig. 33).—The form of this spiculum is very like that of the common edible mushroom when fully grown. The large discal end is convex externally, and has the margin entire. The shaft is nearly of the same diameter throughout its length, and occasionally it has one or two large spines projected from it, near the middle and at right angles to its axis.

The small end is more or less lentiform, but it is frequently very irregular both in size and shape.

This interesting form of spiculum is from the gemmule of *Spongilla reticulata*, Bowerbank, MS. From the River Amazon.

Boletiform: slender (Plate XXVI. figs. 34 and 35).—This graceful and elegant form of spiculum occurs at the inner surface of the crust of the gemmule of *Spongilla recurvata*, Bowerbank, MS., from the River Amazon. The shaft is exceedingly slender, measuring at the middle $\frac{1}{35000}$th of an inch in diameter. The large discal end of the spiculum is slightly convex externally, has the margin perfectly entire, and is $\frac{1}{1017}$th of an inch in diameter. The small lentiform end measured $\frac{1}{6000}$th of an inch in diameter, and the total length of the spiculum is $\frac{1}{707}$th of an inch.

Umbonato-scutulate (Plate XXVI. figs. 36 and 37).—This spiculum is found immediately beneath the outer membrane of the gemmule of a new species of freshwater sponge, from the River Amazon, *Spongilla Brownii*, Bowerbank, MS. The form is truly that of a little shield, the lower surface being concave, while the upper one has a corresponding degree of convexity, and the umbo projects from its centre in the shape of a small cone. The diameter of an average-sized one is $\frac{1}{1500}$th of an inch, and the height very nearly equalled the diameter.

Inequi-tribotulate (Plate XXVI. fig. 38).—Having two terminal rotulæ of equal size, and one intermediate of greater diameter than the terminal ones. I have no knowledge of the sponge from which this spiculum is derived, nor in truth whether it be from a sponge. I found two of them among a great variety of sponge spicula procured by washing some specimens of *Oculina rosea*, from the South Sea. The general structure of the spiculum is the same as that of a Birotulate one from a *Spongilla*, and the rotulæ exhibit, rather indistinctly, the same description of radial canals that are so distinctly portrayed in Plate XXVI. fig. 32. It may possibly have been disengaged by decomposition from the gemmule of some unknown species of *Spongilla* brought down the rivers which discharge their contents in the estuaries, or between the islands of those seas.

3rd. SPICULA DISPOSED IN FASCICULI IN THE SUBSTANCE OF THE GEMMULE FROM THE CENTRE TO THE CIRCUMFERENCE.

INEQUI-FUSIFORMI-ACERATE (Plate XXVI. fig. 39).—This form is found in the fasciculi of spicula that radiate in all directions from the centre to the surface of the gemmules of *Tethea cranium*, JOHNSTON. The largest diameter of the spiculum is at about one-fourth or one-fifth of its length from its base, and thence it gradually diminishes in size to the very attenuated apex. They are about $\frac{1}{50}$th of an inch in length.

UNIHAMATE ATTENUATO-CLAVATE (Plate XXVI. fig. 40).—This singular form occurs abundantly in the gemmules of *Tethea cranium*, JOHNSTON. The long attenuated shaft increases gradually in size from its proximal end to its distal one, where it rapidly but progressively increases in diameter, and terminates hemispherically. From this clavate mass a single hook is projected, which curves slightly towards the shaft of the spiculum, so that its apex reaches a point at about 45° from the axis of the spiculum. The length of the hook is about equal to the diameter of the clavate mass from which it emanates. I have seen a great number of spicula of this form from different specimens of *Tethea cranium*, and never found more than one terminal hook; but it appears highly probable, from a comparison of these spicula with allied forms from the gemmules of *Tethea similimus*, BOWERBANK, MS., from the South Sea, in the Museum of the Royal College of Surgeons, that it is but a permanent variety of the recurvo-ternate form that occurs sparingly among the defensive spicula of *T. cranium*.

ATTENUATO-RECURVO-TERNATE (Plate XXVI. figs. 41 and 42).—In the gemmules of *Tethea similimus*, BOWERBANK, MS., from the South Sea. There are numerous spicula like those represented by figure 40, from *T. cranium*, but not quite so much recurved, and many of these have the rudimentary canal opposite to the well-developed hook, indicating a predisposition to eliminate a second one. In other spicula we find the second hook fully produced, as represented by figure 41; and occasionally, though rarely, we find a completely ternate termination, as represented by figure 42.

ATTENUATO-PORRECTO-TERNATE (Plate XXVI. fig. 43).—This form is found in abundance in the fasciculi of spicula in the gemmule of *Tethea cranium*, JOHNSTON. It is very like the porrecto-ternate spicula that are projected from the surface of that sponge, but it differs from them in always having the radii expanded to a greater amount, in many cases attaining an angle of nearly 40 degrees to the shaft of the spiculum. The ternate termination is always the distal one.

The positions in the sponge of the whole of the spicula hitherto figured have been determined with as great a degree of accuracy as circumstances permitted. Beside these there are other interesting forms of spicula, of the spongeous origin of which there can be no reasonable doubt, which have presented themselves during the course of my researches, and which I have thought it advisable to describe separately.

Spicula, the position of which are unknown.

BIRECURVO-QUATERNATE: MEDIALLY SPINED (Plate XXVI. fig. 44).—This spiculum is figured and described by my friend Prof. QUEKETT in the 'Catalogue of the Histological Series in the Museum of the Royal College of Surgeons,' plate 11. fig. 9 *b*, p. 187. A, p. 46, as a recurvo-ternate form, but a careful examination of three specimens, for which I am indebted to him, has satisfied me that the terminations are quaternate. The two ends of the spiculum differ considerably in structure. At one termination there is little or no enlargement of the shaft, and the hooks are projected somewhat upward as well as outward, and are so curved that each forms nearly a semicircle; while those at the opposite end each curves downward from its base to its apex, describing not more than the fourth part of a circle; and this end of the spiculum has the shaft stronger and more clavate than the other. The spines on the shaft are more or less curved in accordance with the hooks of the larger end. From these characters I am inclined to believe that the spiculum is an internal defensive one, and that the smaller end, the least recurved, is the basal one. The two perfect spicula in my possession were as nearly as possible of the same size, $\frac{1}{100}$th of an inch in length. It was obtained from some spongeous matter taken from the base of a large cup-shaped sponge in the Museum at Edinburgh.

TUBERCULATED FUSIFORMI-CYLINDRICAL (Plate XXVI. fig. 45).—This beautiful spiculum is siliceous. It has been repeatedly found in the matter obtained by washing the roots of *Oculina rosea* and other corals from the South Sea, by my friends Messrs. MATTHEW MARSHALL, LEGG and INGALL, but the sponge, whence it is most probably derived, has never yet been determined. It is remarkable as being the only well-defined and perfect siliceous spiculum that has yet been observed to possess the short stout tubercles that are so characteristic of its structure. Fragments of two other spicula, possessing similar characters, have been observed by me, and are represented by figures 46 and 47. In the specimen represented by figure 46, the tubercles are less in number, but are considerably more produced, and their terminations are more abruptly truncated. In the spiculum represented by figure 47, they are still more widely distributed, are shorter and more inclined to be conical, so that there is little doubt that they have belonged to three distinct species of sponge. But in all three of them there is one peculiarity, that of the manner of the disposition of the tubercles on the shafts of the spicula, where we observe them to be disposed in more or less regular longitudinal lines, and that the tubercles forming each line alternate with those of the line next to them, so that they assume the appearance of a spiral arrangement. The close alliance in the structure of these spicula would seem to indicate the existence of a peculiar tribe of sponges, with which we are at present entirely unacquainted.

ACERATE: VERTICILLATELY SPINED (Plate XXVI. fig. 48).—I obtained this singular form from a parasitical sponge from Western Australia. This curious sponge, in the formation of its skeleton, appears to have appropriated the spicula of every other kind of sponge that came within its reach, and among a great variety of forms I found several of the

same description as that represented by figure 48. From its general character, I am inclined to believe that it belongs to the sarcode.

SPINULATO-ENSIFORM (Plate XXVI. fig. 49).—I have never found this spiculum *in situ*. A few specimens were obtained from the same sponge from which the spiculum represented by fig. 48 was taken.

ACUATE: BASALLY RECTANGULATED (Plate XXVI. fig. 50).—I obtained this spiculum from the spongeous matter scraped from the base of *Oculina rosea*, by a dealer in the process of cleaning the coral. It is not a malformation, as there are several of them in the same slide, and they are all angulated to the same extent. It is probably an internal defensive spiculum.

SUBSPINULATO-ARCUATE (Plate XXVI. fig. 51).—I obtained this singular form of spiculum from my friend Mr. THOMAS INGALL, a zealous and liberal investigator of the Spongiadæ. It is said to be from Ash Island, New South Wales. When well-developed, both the terminations of the cylindrical shaft are more or less spinulate, and one or both of the ends of the shaft are incipiently spinous.

The nearest form to this spiculum is the arcuate one that is found on the surface of the gemmule of *Spongilla lacustris*, JOHNSTON, and it is probable that this one is also from a sponge of that genus, as I have never seen any spicula of that form in any marine sponge from Australia.

EXPLANATION OF THE PLATES.

PLATE XXIII.

Structure of Spicula.

Fig. 1. Distal termination of a porrecto-ternate spiculum from *Tethea cranium*, with angular distortions from external pressure, ×260 linear: page 282.

Fig. 2. A portion of an adult spiculum from *Spongilla fluviatilis*, charred to exhibit the thin membrane of the central cavity of the spiculum, ×260 linear: page 282.

Fig. 3. A portion of an immature spiculum from *Spongilla lacustris*, charred to exhibit the dense membrane lining the large central cavity in the young spiculum, ×260 linear: page 282.

Fig. 4. A section at right angles to the axis of the upper part of the shaft of a ternate spiculum from *Geodia Barretti*, BOWERBANK, MS., exhibiting the concentric layers, ×260 linear: page 282.

Figs. 5 and 6. Portions of charred spicula from the skeleton fasciculi of *Tethea cranium*, exhibiting their hollow condition after incineration, ×90 linear: page 283.

Fig. 7. A portion of a spiculum from *Euplectella aspergillum*, slightly charred, exhibiting the concentric layers of silex, ×90 linear: page 284.

Fig. 8. A portion of an adult spiculum from the skeleton of *Geodia M'Andrewii*,

BOWERBANK, MS., cracked by the application of cold water while in a heated state, ×90 linear: page 284.

Spicula of the Skeleton.

Fig. 9 *a*. ACERATE, from *Halichondria panicea*, JOHNSTON, ×160 linear: page 286.

Fig. 9 *b*. ACERATE, from *Spongilla fluviatilis*, JOHNSTON, ×160 linear: page 286.

Fig. 10. FUSIFORMI-ACERATE, from *Halichondria coccinea*, BOWERBANK, MS., ×160 linear: page 286.

Fig. 11. INFLATO-FUSIFORMI-ACERATE, *Isodictya anomala*, BOWERBANK, MS., ×160 linear: page 286.

Fig. 12 *a*. ACUATE, from *Halichondria Alderi*, BOWERBANK, MS., ×160 linear: page 286.

Fig. 12 *b*. ACUATE, from *Halichondria caruncula*, BOWERBANK, MS., ×160 linear: page 286.

Fig. 13. FUSIFORMI-ACUATE, from *Halichondria crustula*, BOWERBANK, MS., ×160 linear: page 286.

Fig. 14. ATTENUATO-ACUATE, from *Halichondria infundibuliformis*, JOHNSTON, ×160 linear: page 286.

Fig. 15. FLECTO-ATTENUATO-ACUATE, from *Halichondria infundibuliformis*, JOHNSTON, ×160 linear: page 286.

Fig. 16. FLECTO-ATTENUATO-ACUATE, from *Halichondria variantia*, BOWERBANK, MS., ×160 linear: page 286.

Fig. 17. CYLINDRICAL, from *Pachymatisma Johnstonia*, BOWERBANK, ×90 linear: page 287.

Fig. 18. FUSIFORMI-CYLINDRICAL, from *Pachymatisma Johnstonia*, BOWERBANK, ×90 linear: page 287.

Fig. 19. ATTENUATO-CYLINDRICAL, from *Pachymatisma Johnstonia*, BOWERBANK, ×90 linear: page 287.

Fig. 20. FUSIFORMI-ATTENUATO-CYLINDRICAL, from *Tethea robusta*, BOWERBANK, MS., ×90 linear: page 287.

Fig. 21. BICLAVATED CYLINDRICAL, from a new Australian sponge, ×260 linear: page 287.

Fig. 22. INEQUI-BICLAVATED CYLINDRICAL, from *Pachymatisma Johnstonia*, BOWERBANK, ×90 linear: page 287.

Fig. 23. ANGULATED INEQUI-BICLAVATED CYLINDRICAL, from *Pachymatisma Johnstonia*, BOWERBANK, ×90 linear: page 287.

Fig. 24. SPINULATE, from *Halichondria carnosa*, JOHNSTON, ×260 linear: page 287.

Fig. 25. FUSIFORMI-SPINULATE, from *Halichondria suberea*, JOHNSTON, ×260 linear: page 287.

Fig. 26. ATTENUATO-DEPRESSO-SPINULATE, from an undescribed species of sponge, ×160 linear: page 287.

Fig. 27. ENORMI-SPINULATE, from *Halichondria celata*, JOHNSTON, ×260 linear: page 287.

Fig. 28. FLEXUOUS, from *Halichondria ventilabrum*, JOHNSTON, ×160 linear: page 287.

Fig. 29. ENSIFORM, from an unknown sponge, ×130 linear: page 287.

Fig. 30. Spiculum, ENTIRELY SPINED, from *Halichondria incrustans*, JOHNSTON, ×260 linear: page 288.

Fig. 31. Spiculum, BASALLY SPINED, from *Halichondria Ingalli*, BOWERBANK, MS., ×260 linear: page 288.

Fig. 32. Spiculum, MEDIALLY SPINED, from *Halichondria Ingalli*, BOWERBANK, MS., ×260 linear: page 288.

Fig. 33. Spiculum, APICALLY SPINED, from an undescribed sponge, ×160 linear: page 288.

Fig. 34. Spiculum, TERMINALLY SPINED, from an undescribed sponge, ×160 linear: page 288.

Fig. 35. EQUIANGULAR TRIRADIATE, from *Grantia compressa*, FLEMING, ×160 linear: page 288.

Fig. 36. RECTANGULAR TRIRADIATE, *Grantia tessellata*, BOWERBANK, MS., ×260 linear: page 288.

Fig. 37. EQUIANGULAR TRIRADIATE, a very stout variety of form, from an undescribed African sponge, ×90 linear: page 288.

Fig. 38. EQUIANGULAR SPICULATED TRIRADIATE, from *Halina Bucklandi*, BOWERBANK, MS., ×90 linear: page 288.

Fig. 39. BIANGULATED QUADRIRADIATE, from *Halina Bucklandi*, BOWERBANK, MS., ×90 linear: page 289.

Fig. 40. TRIFURCATED PATENTO-BITERNATE, from an undescribed sponge, ×90 linear: page 289.

Fig. 41. A view of the end of one of the same spicula as that represented by fig. 40, ×90 linear: page 289.

Connecting Spicula.

Fig. 42. ATTENUATO-EXPANDO-TERNATE, from *Pachymatisma Johnstonia*, BOWERBANK, ×90 linear: page 289.

Fig. 43. CYLINDRO-EXPANDO-TERNATE, from *Pachymatisma Johnstonia*, BOWERBANK, ×90 linear: page 290.

Fig. 44. PATENTO-TERNATE, from *Geodia McAndrewii*, BOWERBANK, MS., ×90 linear: page 290.

Fig. 45. RECURVO-TERNATE, from *Geodia Barretti*, BOWERBANK, MS., ×90 linear: page 290.

Fig. 46. FURCATED ATTENUATO-PATENTO-TERNATE, from *Pachymatisma Listeri*, BOWERBANK, MS., ×90 linear: page 290.

Fig. 47. A view of the ternate termination of one of the same spicula represented by fig. 46, ×90 linear: page 290.

Fig. 48. SPICULATED DICHOTOMO-PATENTO-TERNATE. Sponge unknown, ×260 linear: page 290.

Fig. 49. SPICULATED PORRECTO-TERNATE, from *Geodia M'Andrewii*, BOWERBANK, MS., ×90 linear: page 291.

Fig. 50. SPICULATED RECURVO-TERNATE, from *Geodia Barretti*, BOWERBANK, MS., ×90 linear: page 291.

Fig. 51. SPICULATED RECURVO-TERNATE, having the spiculate ray deflected from the axial line, from *Geodia Barretti*, ×90 linear: page 291.

Fig. 52. RECURVO-TERNATE, having one of the rays distorted upwards, from *Geodia Barretti*, ×90 linear: page 291*.

Prehensile Spicula.

Fig. 53. APICALLY SPINED RECURVO-QUATERNATE, from *Euplectella cucumer*, OWEN, ×90 linear: page 291.

PLATE XXIV.

Defensive Spicula.

Fig. 1. ATTENUATO-ACUATE. ENTIRELY SPINED, from *Dictyocylindrus ventilabrum*, BOWERBANK, MS., ×260 linear: page 293.

Fig. 2. ACUATE, ENTIRELY AND VERTICILLATELY SPINED, from an undescribed sponge, ×400 linear: page 293.

Fig. 3. CYLINDRICAL, ENTIRELY AND VERTICILLATELY SPINED. Sponge unknown, ×400 linear: page 293.

Fig. 4. SPINULO-RECURVO-QUATERNATE, first stage of development, ×130 linear: page 294.

Fig. 5. The same spiculum as fig. 4 in the second stage of development, ×130 linear: page 294.

Fig. 6. The same spiculum as fig. 4 in the third stage of development, ×130 linear: page 294.

Fig. 7. The same spiculum as represented by fig. 4, but in a completely developed state. Sponge undescribed, ×130 linear: page 294.

Fig. 8. FUSIFORMI-PORRECTO-TERNATE, a very early stage of development, from *Tethea cranium*, JOHNSTON, ×660 linear: page 295.

Fig. 9. A further stage of development of a fusiformi-porrecto-ternate spiculum from *Tethea cranium*, ×260 linear: page 295.

Fig. 10. An adult fusiformi-porrecto-ternate spiculum from *Tethea cranium*, ×160 linear: pages 289 and 295.

Fig. 11. A fusiformi-porrecto-ternate spiculum from *Tethea cranium*, charred to exhibit the cavities of the shaft and radii, ×260 linear: page 295.

Fig. 12. FUSIFORMI-RECURVO-TERNATE spiculum, in an early stage of development, from *Tethea cranium*, JOHNSTON, ×260 linear: page 295.

* The number of the figure in page 291 is erroneously printed 53 instead of 52.

Fig. 13. FUSIFORMI-RECURVO-TERNATE, an adult spiculum from the same sponge as the spiculum represented by fig. 12, ×260 linear: page 295.

Fig. 14. SPICULATED EQUIANGULATED TRIRADIATE, from *Grantia nivea*, JOHNSTON, ×45 linear: page 295.

Fig. 15. ENSIFORM SPICULATED EQUIANGULATED TRIRADIATE, from *Grantia ensata*, BOWERBANK, MS., ×130 linear: page 296.

Fig. 16. ENSIFORM SPICULATED EQUIANGULATED TRIRADIATE, from *Grantia tessellata*, BOWERBANK, MS., ×130 linear: page 296.

Fig. 17. EQUIANGULATED SPICULATED TRIPODATE, from *Grantia nivea*, JOHNSTON, ×660 linear: page 296.

Fig. 18. EQUIANGULATED TRIRADIATED, UNIRADIALLY SPINED, from an undescribed sponge, ×130 linear: page 296.

Fig. 19. ATTENUATO-CLAVATE, INCIPIENTLY SPINED, from *Hymeniacidon clavigera*, BOWERBANK, MS., ×130 linear: page 296.

Fig. 20. EQUIANGULATED TRIRADIATE, VERTICILLATELY SPINED. Sponge unknown, ×400 linear: page 296.

Spicula of the Membranes.—Tension Spicula.

Fig. 21. FUSIFORMI-ACERATE, ENTIRELY SPINED, from *Spongilla lacustris*, JOHNSTON, ×660 linear: page 297.

Fig. 22. FUSIFORMI-ACERATE, TRUNCATEDLY SPINED, from *Spongilla alba*, CARTER, ×660 linear: page 297.

Fig. 23. MUCRONATO-CYLINDRICAL, from *Halichondria incrustans*, JOHNSTON, ×400 linear: page 297.

Fig. 24. TUBERCULATED FUSIFORMI-CYLINDRICAL, from *Pachymatisma Johnstonia*, BOWERBANK, ×660 linear: page 298.

Fig. 25. INFLATO-CYLINDRICAL, from *Halichondria ficus*, JOHNSTON, ×660 linear: page 298.

Figs. 26, 27, 28. TRICURVO-ACERATE, from an undescribed sponge in the cabinet of Mr. THOMAS INGALL, ×260 linear: page 298.

Fig. 29. UNICURVO-CRUCIFORM, from *Grantia nivea*, JOHNSTON, ×130 linear: page 298.

Fig. 30. FALCATO-ACERATE, from an undescribed species of *Grantia* on several species of *Fuci* brought from Australia by Dr. HARVEY, ×130 linear: page 298.

Fig. 31. BICURVO-ACERATE, from a small undescribed species of *Grantia* from Algoa Bay, ×260 linear: page 298.

Fig. 32. FOLIATO-PELTATE, first stage of development, exhibiting rudimentary simple triradiate canals, ×260 linear: page 299.

Fig. 33. FOLIATO-PELTATE, second stage of development, ×160 linear: page 299.

Fig. 34. FOLIATO-PELTATE, third stage of development, ×160 linear: page 299.

Fig. 35. FOLIATO-PELTATE, fourth stage of development, ×160 linear: page 299.

Fig. 36. FOLIATO-PELTATE, an adult spiculum fully developed, ×130 linear: page 299.

Fig. 37. FOLIATO-PELTATE,, a side view of a spiculum, exhibiting the form and comparative length of the shaft, ×160 linear: page 299.

Fig. 38. FOLIATO-PELTATE, a fragment exhibiting furcated terminations to two out of the three radiating canals, ×260 linear: page 299.

Retentive Spicula.

Fig. 39. SIMPLE BIHAMATE, from *Halichondria variantia*, BOWERBANK, MS. British, ×1060 linear: page 300.

Fig. 40. REVERSED BIHAMATE, from *Halichondria incrustans*, JOHNSTON, ×1066 linear: page 300.

Fig. 41. CONTORT BIHAMATE, from *Halichondria incrustans*, JOHNSTON, ×1066 linear: page 300.

Fig. 42. ABBREVIATED BIHAMATE, from an unknown sponge, ×1060 linear: page 301.

Fig. 43. DEFLECTED BIHAMATE, from the spongeous mass at the base of *Euplectella cucumer*, OWEN, ×660 linear: page 301.

Fig. 44. EXTER-UMBONATE, from an undescribed sponge from Sicily, ×1060 linear: page 301.

Fig. 45. INTER-UMBONATE, from the same sponge as fig. 44, ×1060 linear: page 301.

Fig. 46. BI-UMBONATE, from the same sponge as fig. 44, ×1060 linear: page 301.

Figs. 47, 48 and 49. CLAVATED BIHAMATE, from the same sponge as fig. 44, ×1060 linear: page 302.

Fig. 50. UNIPOCILLATED BIHAMATE, from *Halichondria Hyndmani*, BOWERBANK, MS., ×1060 linear: page 302.

Fig. 51. SIMPLE BIPOCILLATED BIHAMATE, from *Halichondria Hyndmani*, BOWERBANK, MS., ×1060 linear: page 302.

Fig. 52. CONTORT BIPOCILLATED BIHAMATE, from *Halichondria Hyndmani*, BOWERBANK, MS., ×1060 linear: page 302.

Fig. 53. UMBONATED BIPOCILLATED BIHAMATE, from *Halichondria Hyndmani*, BOWERBANK, MS., ×1060 linear: page 303.

Fig. 54. A view in profile of a unipocillated spiculum, illustrating the production of the umbo, from *Halichondria Hyndmani*, BOWERBANK, MS., ×1060 linear: page 303.

Fig. 55. BIDENTATE INEQUI-ANCHORATE, from an undescribed sponge from the coast of Sicily, ×660 linear: page 305.

Fig. 56. PALMATED INEQUI-ANCHORATE, from an undescribed sponge, ×660 linear: page 305.

Fig. 57. TRIDENTATE EQUI-ANCHORATE, from an undescribed sponge in the cabinet of Mr. GEORGE SHADBOLT, ×660 linear: page 305.

Fig. 58. DENTATO-PALMATE INEQUI-ANCHORATE, from *Spongia lobata*, MONTAGU, *Isodictya lobata*, BOWERBANK, MS., ×1060 linear: page 306.

PLATE XXV.

Fig. 1. DENTATO-PALMATE ANGULATED ANCHORATE, from *Spongia lobata*, MONTAGU, *Halichondria lobata*, JOHNSTON, an adult spiculum, ×1060 linear: page 306.

Fig. 2. DENTATO-PALMATE ANGULATED ANCHORATE, an immature specimen, from the same sponge as fig. 1, ×1060 linear: page 306.

Fig. 3. DENTATO-PALMATE ANGULATED ANCHORATE, from the same sponge as fig. 1; a view in profile to exhibit the angulated character of the hami, ×1060 linear: page 306.

Fig. 4. DENTATO-PALMATE INEQUI-ANCHORATE, first stage of development, ×260 linear: page 304.

Fig. 5. DENTATO-PALMATE INEQUI-ANCHORATE, second stage of development, ×260 linear: page 304.

Fig. 6. DENTATO-PALMATE INEQUI-ANCHORATE, third stage of development, ×260 linear: page 305.

Fig. 7. DENTATO-PALMATE INEQUI-ANCHORATE, an adult spiculum, showing the fully-produced distal terminal hastate tooth, ×260 linear: page 305.

Fig. 8. DENTATO-PALMATE INEQUI-ANCHORATE, from the same sponge as fig. 7, showing the effects of incomplete development or malformation, ×260 linear.

Spicula of the Sarcode.

Fig. 9. ATTENUATO-STELLATE, from *Pachymatisma Johnstonia*, BOWERBANK, MS., ×660 linear: page 307.

Fig. 10. CYLINDRO-STELLATE, from *Pachymatisma Johnstonia*, BOWERBANK, ×660 linear: page 307.

Fig. 11. CRASSATO-CYLINDRO-STELLATE, from *Tethea robusta*, BOWERBANK, MS., ×1060 linear: page 307.

Fig. 12. CLAVATED SUBSPHERO-STELLATE, from *Tethea Ingalli*, BOWERBANK, MS., ×1060 linear: page 307.

Fig. 13. CLAVATED SPHERO-STELLATE, from *Geodia Barretti*, BOWERBANK, MS., ×1060 linear: page 307.

Fig. 14. SUBSPHERO-STELLATE, from *Tethea Ingalli*, BOWERBANK, MS., ×660 linear: page 307.

Fig. 15. SPHERO-STELLATE, from *Tethea robusta*, BOWERBANK, MS., ×660 linear: page 308.

Fig. 16. SPHERO-STELLATE, WITH CYLINDRICAL SUBFOLIATE RADII, from an unknown sponge, ×400 linear: page 308.

Fig. 17. A SPHERO-STELLATE SPICULUM, exhibiting the central canals in the radii, ×660 linear: page 308.

Fig. 18. ELONGO-ATTENUATO-STELLATE, from *Tethea muricata*, BOWERBANK, MS., ×1060 linear: page 308.

Fig. 19. ARBORESCENT ELONGO-SUBSPHERO-STELLATE, from *Geodia carinata*, BOWERBANK, MS., ×1060 linear: page 308.

Figs. 20, 21, 22 and 23. PILEATED CYLINDRO-STELLATE, in progressive stages of development, ×660 linear: page 308.

Compound Stellate Spicula.

Fig. 24. ATTENUATED RECTANGULATED HEXRADIATE, from *Euplectella aspergillum*, OWEN; first stage of development, exhibiting only the primary or axial radii, ×90 linear: page 309.

Figs. 25, 26 and 27. Progressive degrees of development of the secondary radii of the same form of spiculum represented by fig. 24, ×90 linear: page 309.

Fig. 28. The same spiculum as fig. 24, with one secondary ray fully developed, ×90 linear: page 309.

Fig. 29. The same spiculum as fig. 24, having two secondary rays forming a right angle with each other, fully developed, ×90 linear: page 309.

Fig. 30. The same spiculum as fig. 24, with two secondary rays developed in opposite directions, ×90 linear: page 309.

Fig. 31. The same spiculum as fig. 24, with three secondary rays forming two right angles with each other, ×90 linear: page 309.

Fig. 32. A fully developed attenuated rectangulated hexradiate spiculum, ×90 linear: page 309.

Fig. 33. The same form of spiculum as fig. 32, with the whole of the secondary radii fully developed, but with one only of the axial radii produced, ×90 linear: page 309.

Fig. 34. SLENDER ATTENUATED RECTANGULATED HEXRADIATE, from *Euplectella aspergillum*, OWEN, ×90 linear: page 310.

Fig. 35. CYLINDRO-RECTANGULATED HEXRADIATE, APICALLY SPINED, from a specimen of *Euplectella* in the Museum of the Jardin des Plantes, Paris, ×130 linear: page 310.

Fig. 36. One of the radii of the spiculum represented by fig. 35, exhibiting the spination of the apices, ×400 linear: page 310.

Fig. 37. Part of the axial shaft of a cylindro-rectangulated hexradiate spiculum, exhibiting the parts from which the radii would be produced, from the *Euplectella* in the Museum of the Jardin des Plantes, Paris, ×400 linear: page 310.

Fig. 38. BIFURCATED RECTANGULATED HEXRADIATE STELLATE, from the *Euplectella* in the Museum of the Jardin des Plantes, Paris, ×1060 linear: page 311.

Fig. 39. TRIFURCATED ATTENUATO-HEXRADIATE, from *Euplectella aspergillum*, OWEN, having the ray nearest the eye broken off at its base, ×1060 linear: page 311.

PLATE XXVI.

Fig. 1. SPINULO-TRIFURCATED HEXRADIATE STELLATE, from *Dactylocalyx pumicea*, STUTCHBURY, a perfect spiculum, ×1060 linear: page 311.

Fig. 2. SPINULO-QUADRIFURCATE HEXRADIATE STELLATE, from a species of *Dactylocalyx*, STUTCHBURY, in the Cabinet of Mr. THOMAS INGALL, ×1060 linear: page 312.

Fig. 3. FLORICOMO-HEXRADIATE, from *Euplectella aspergillum*, OWEN, in the Cabinet of Mr. HUGH CUMING, showing four out of the six primary radii, and the mode of the attachment of the secondary ones to their distal terminations, ×660 linear: page 312.

Fig. 4. FLORICOMO-HEXRADIATE, from the same sponge as fig. 3, exhibiting a front view of the congregated expanded apices of one of the groups of the secondary radii, and the contour of a perfect spiculum, ×660 linear: page 312.

Fig. 5. CORONATO-HEXRADIATE STELLATE, from a species of *Euplectella* in the Museum of the Jardin des Plantes, Paris, ×1060 linear: page 312.

Fig. 6. POCILLATED HEXRADIATE STELLATE. Sponge unknown, ×1060 linear: page 313.

Fig. 7. ATTENUATO-RECTANGULATED TRIRADIATE, APICALLY SPINED, from *Euplectella aspergillum*, ×90 linear: page 313.

Figs. 8 and 9. SPICULATED BITERNATE, from a siliceo-fibrous sponge in the possession of Dr. A. FARRE. Fig. 8 ×90 linear; fig. 9 ×130 linear: page 313.

Fig. 10. MULTIANGULATED CYLINDRICAL, from *Geodia carinata*, BOWERBANK, MS., ×660 linear: page 314.

Spicula of the Gemmules.

Fig. 11. ACERATE, from *Spongilla Carteri*, BOWERBANK, MS., ×130 linear: page 315.

Fig. 12. ACERATE, from *Spongilla Brownii*, BOWERBANK, MS., ×130 linear: page 315.

Fig. 13. SUBARCUATE ACERATE, from *Spongilla lacustris*, JOHNSTON, ×660 linear: page 315.

Fig. 14. FUSIFORMI-ACERATE, entirely spined, spines cylindrical, from *Spongilla Batei*, BOWERBANK, MS., ×660 linear: page 315.

Fig. 15. ACERATE, ENTIRELY SPINED, SPINES CONICAL, from *Spongilla cinerea*, CARTER, ×660 linear: page 315.

Fig. 16. CYLINDRICAL, INCIPIENTLY SPINED, from *Spongilla gregarea*, BOWERBANK, MS., ×400 linear: page 316.

Fig. 17. CYLINDRICAL, ENTIRELY AND RECURVEDLY SPINOUS: spines of the middle cylindrical, those of the terminations conical and recurved, from *Spongilla cinerea*, CARTER, ×400 linear: page 316.

Fig. 18. First stage of development of a birotulate spiculum from the gemmule of *Spongilla plumosa*, CARTER, ×660 linear: page 317.

Fig. 19. Second stage of development of a birotulate spiculum from the gemmule of *Spongilla plumosa*, CARTER, ×660 linear: page 317.

Fig. 20. Third stage of development of a birotulate spiculum from the gemmule of *Spongilla plumosa*, CARTER, ×660 linear: page 317.

Fig. 21. ADULT RECURVO-DENTATE BIROTULATE SPICULUM, shaft entirely spined, from the gemmule of *Spongilla plumosa*, CARTER, ×660 linear: page 318.

Fig. 22. A view of the inner surface of one of the rotulæ of the spiculum represented by fig. 21, showing the amount and irregularity of the dentation of its margin, ×660 linear: page 318.

Fig. 23. BIROTULATE, MARGINS OF THE ROTULÆ ENTIRE, from *Spongilla gregarea*, BOWERBANK, MS. A side view of an averaged-sized specimen, ×1100 linear: page 317.

Fig. 24. A view of the external surface of one of the rotulæ of the same form of spiculum as that represented by fig. 23, ×1100 linear: page 317.

Fig. 25. A young imperfectly developed spiculum of the same description as represented by fig. 23, ×1100 linear: page 317.

Fig. 26. A spiculum of the same description as represented by fig. 23, developed to a greater extent than usual, ×660 linear: page 317.

Fig. 27. BIROTULATE, ROTULÆ IRREGULARLY AND DEEPLY DENTATE, from *Spongilla fluviatilis*, JOHNSTON, ×660 linear: page 317.

Fig. 28. A view of the external surface of one of the rotulæ of the same description of spiculum represented by fig. 27, ×660 linear: page 317.

Fig. 29. BIROTULATE, ROTULÆ IRREGULARLY AND DEEPLY DENTATE, shaft medially spined, from *Spongilla Meyeni*, CARTER, ×660 linear: page 318.

Fig. 30. MULTIHAMATE BIROTULATE, from the gemmules of *Spongilla recurvata*, BOWERBANK, MS., ×660 linear: page 318.

Fig. 31. INEQUI-BIROTULATE, from the gemmule of *Spongilla paulula*, BOWERBANK, MS., ×660 linear: page 318.

Fig. 32. View of the inner surface of a large rotula of an inequi-birotulate spiculum from *Spongilla paulula*, showing the radiating canals, ×1060 linear: page 318.

Fig. 33. BOLETIFORM, from gemmule of *Spongilla reticulata*, BOWERBANK, MS., ×660 linear: page 319.

Fig. 34. BOLETIFORM, SLENDER, from the gemmule of *Spongilla recurvata*, BOWERBANK, MS., ×660 linear: page 319.

Fig. 35. View of the inner surface of a rotula of a slender boletiform spiculum from *Spongilla recurvata*, BOWERBANK, MS., ×660 linear: page 319.

Fig. 36. UMBONATO-SCUTULATE, from *Spongilla Brownii*, BOWERBANK, MS. View of external surface, ×660 linear: page 319.

Fig. 37. UMBONATO-SCUTULATE, from *Spongilla Brownii*, BOWERBANK, MS. Side view, showing length and form of the umbo, ×660 linear: page 319.

Fig. 38. INEQUI-TRIROTULATE. Sponge unknown, ×660 linear: page 319.

Fig. 39. INEQUI-FUSIFORMI-ACERATE, from the gemmule of *Tethea cranium*, JOHNSTON, ×130 linear: page 320.

Fig. 40. UNIHAMATE ATTENUATO-CLAVATE, from the gemmule of *Tethea cranium*, JOHNSTON, ×260 linear: page 320.

Fig. 41. A bihamate variety of a recurvo-ternate spiculum from *Tethea similimus*, BOWERBANK, MS., ×660 linear: page 320.

Fig. 42. ATTENUATO-RECURVO-TERNATE, from *Tethea similimus*, BOWERBANK, MS., ×660 linear: page 320.

Fig. 43. ATTENUATO-PORRECTO-TERNATE, from the gemmule of *Tethea cranium*, JOHNSTON, ×130 linear: page 320.

Spicula, the position of which are unknown.

Fig. 44. BIRECURVO-QUATERNATE, MEDIALLY SPINED. Sponge unknown, ×660 linear: page 321.

Fig. 45. TUBERCULATED FUSIFORMI-CYLINDRICAL. Sponge unknown, ×150 linear: page 321.

Fig. 46. Tuberculated spiculum. Sponge unknown, ×260 linear: page 321.

Fig. 47. Tuberculated spiculum. Sponge unknown, ×260 linear: page 321.

Fig. 48. ACERATE, VERTICILLATELY SPINED, from a parasitical sponge from Western Australia, ×130 linear: page 321.

Fig. 49. SPINULATO-ENSIFORM, from a parasitical sponge from Western Australia, ×130 linear: page 322.

Fig. 50. ACUATE, BASALLY RECTANGULATED. Sponge unknown, ×150 linear: page 322.

Fig. 51. SUBSPINULATO-ARCUATE. Sponge unknown, ×260 linear: page 322.

XVII. *On the Physical Structure of the Old Red Sandstone of the County of Waterford, considered with relation to Cleavage, Joint Surfaces, and Faults.* By the Rev. SAMUEL HAUGHTON, *M.A., F.G.S., Fellow of Trinity College, and Professor of Geology in the University of Dublin. Communicated by Professor* TYNDALL, *F.R.S.*

Received January 19,—Read January 21, 1858.

CONTENTS:—

1. Description of the District.
2. Faults.
3. Joint Planes.
4. Cleavage Planes.
5. Observations Tabulated.

1. *Description of the District.*

IN a paper published by me in the Philosophical Magazine*, I have stated my views in relation to cleavage structure of rocks, considered in connexion with the distortion of fossils, and arrived at the following results:—

1st. That the cleavage is in planes perpendicular to the lines of maximum pressure.

2nd. That the distortion of fossils, in any plane of bedding, depends on the angle made with the plane of cleavage, by the plane of bedding considered; increasing with that angle, according to a law, which I have defined in the paper itself.

During the course of the past summer (1857), I was enabled to study the physical structure of the Old Red Sandstone conglomerate of the county of Waterford; a rock eminently unsuited to the production of cleavage, or indeed, any other phenomena, by the influence of polar forces; and, in the course of my observations, I arrived at facts which appear to me to be inexplicable on any other than a mechanical theory. As the facts themselves are worthy of record, whatever opinion may be formed of the inferences I have deduced from them, and as the observations on which they depend (345) are more numerous than usual, and, as I believe, carefully made, I have felt myself justified in bringing them under the notice of the Royal Society, and thus placing them on record.

The Old Red Sandstone conglomerate of the South-east of the county of Waterford extends in an E.N.E. and W.S.W. direction, from Creadan Head, Waterford Harbour, to Brownstown Head, east of Tramore Bay, a distance of $7\frac{3}{4}$ miles; and in a perpendicular direction, its greatest breadth is about $3\frac{1}{4}$ miles. The average bearing, or strike of the beds of which it is composed, is parallel to the line of greatest length, and it has throughout a dip or inclination towards the sea, ranging from 5° to 20°. Its lowest portion consists of some 200 feet of solid conglomerate, surmounted by varying beds of red sandstone and shale of every degree of mechanical fineness and subdivision. The

* Philosophical Magazine, Fourth Series, vol. xii. p. 409.

observations of cleavage, joint, and fault planes here recorded, are confined to the solid conglomerate itself, as this rock seemed to me, to offer a sort of *experimentum crucis* between the polar and mechanical theories of cleavage and joints.

This conglomerate is composed of numerous rounded pebbles, principally of quartz, with a few of slate, and granite containing white mica, similar to that of the granites of the main chain between Dublin and New Ross (70 miles); the quartz pebbles being generally from 4 to 6 inches in diameter, the whole cemented together by a paste, rarely calcareous, containing abundance of red peroxide of iron, which gives its characteristic colour and name to the entire rock.

About the centre of the coast line between Creadan and Brownstown Heads, is the promontory of Red Head, forming the western entrance into Waterford Harbour, and remarkable as being the central point of the geological elevation of the whole district, inasmuch as the faults to the eastward of Red Head are accompanied by downthrows to the east, while the faults to the westward of Red Head are accompanied by downthrows to the west. There are three distinct kinds of physical planes observable in the Old Red Sandstone conglomerate of this district, on each of which it is necessary to make some remarks. These planes are—1st. Faults; 2nd. Joints; 3rd. Cleavage Planes.

2. *Faults.*

A fault is a plane of division in a rock, along which the separated portions of rock have slipped, either vertically or horizontally, or both; the amount of vertical dislocation is the *downthrow*, and the amount of horizontal displacement is the *heave* of the fault. I determined the position, strike, inclination, and generally the downthrow of twenty faults, which are easily reducible to several systems, very well marked, and having a close connexion with the corresponding systems of joint planes and cleavage planes to be described presently. As some of these systems of faults are at right angles to others, I shall group them together according to their natural relations, as follows:—

System A.

No.	Bearing.	Dip.	Downthrow.	Locality.
1.	E. 10° N.	55° N.	10 feet North.	Portnashrughaun.
2.	E. 5 N.	66 N.	North.	Beenlea, West.
Mean = 7° 30′ North of East (Magnetic).				

System C.

No.	Bearing.	Dip.	Downthrow.	Locality.
1.	N. 10° W.	70° E.	50 feet East.	East side of Red Head.
2.	N. 5 W.	90	6 feet West.	Bishop's Cove.
3.	N. 0 W.	75 W.	20 feet West.	Stony Cove.
4.	N. 0 W.	.....	.....	Kilmaleague.
Mean = 3° 45′ West of North (Magnetic).				

System A′.

No.	Bearing.	Dip.	Downthrow.	Locality.
1.	E. 35° N.	74° N.	10 feet North.	Lady Waterford's Rocks.
2.	E. 35 N.	75 N.	3 feet North.	Lady Waterford's Rocks.
3.	E. 35 N.	90	3 feet North.	Lady Waterford's Rocks.
4.	E. 35 N.	65 N.	1 foot North.	Portnashrughaun.
5.	E. 35 N.	90	5 feet North.	Portnashrughaun.
6.	E. 30 N.	N.	104 feet North.	Old Ship's Cove.
7.	E. 35 N.	80 N.	4 feet North.	East of Swiny Head.
8.	E. 35 N.	60 N.	75 feet North.	Stony Cove.
Mean =34° 22′ North of East (Magnetic).				

System C′.

No.	Bearing.	Dip.	Downthrow.	Locality.
1.	N. 35° W.	53° W.	8 feet West.	Centre of Red Head.
2*.	N. 32 W.	66 E.	3 feet West.	Portnashrughaun.
3.	N. 30 W.	75 W.	6 feet West.	Pusnahooan.
4.	N. 35 W.	60 E.	10 feet East.	East of Cathedral Rocks.
5.	N. 35 W.	80 W.	2 feet West.	Creadan Bay.
Mean =33° 24′ West of North (Magnetic).				

There is one other fault, not referable to any of the foregoing systems; it occurs at Rathmoylan Cove; bearing, N. 40° E.; dip, 70° E.; downthrow, 1 foot eastward: although it appears as an exception at first sight, it will be seen from the discussion of the directions of the joint and cleavage planes, that this fault really belongs to another system of planes which is well developed in other parts of the district. Roughly speaking, it appears that the systems A and C, A′ and C′, have bearings nearly at right angles to each other; the angle between the first two systems being, from East to North, 93° 45′, and the angle between the systems A′ and C′ being 89° 2′.

The most important of the systems of faults, estimated by the amount of dislocation caused by them, are the systems C and A′; the former containing the well-marked downthrow of 50 feet east of Red Head, and the latter containing the two greatest faults in the entire district, viz. 104 feet at Old Ship's Cove, and 75 feet at Stony Cove, both downthrows to the west. If we had no other evidence of the physical structure of the conglomerate than is supplied by the foregoing systems of faults, we should be entitled to conclude that two systems of elevating forces had acted, either simultaneously or in succession, to raise the conglomerate beds to their present dip, and dislocate them along the planes described. The planes of the elevating forces were probably vertical planes, nearly in the azimuths of 5° West of North, and 33° West of North (both magnetic bearings). I have reason to believe that the conjugate system (A, C) has been principally concerned in imparting to the mass of conglomerate its inner or latent structure, which

* This is a reversed fault.

I shall presently describe under the name of cleavage, and that it was the first system of forces that acted upon the coarse shingle of the Old Red Sandstone shore after its deposition; at the same time there is reason to think that the conjugate system (A′, C′) was the most powerful of the two systems of forces. Both were concerned in producing the elevation of the beds, which have an average strike of E. 10° 46′ N., and an average dip of 13° 42′ S. The strike of the beds is thus seen to be intermediate between the systems A and A′, but lying nearest the former, which I conceive to have acted first in order of time.

Throughout this paper I shall speak of planes, or faults, having rectangular bearings, as forming a conjugate system; assuming the well-known mechanical principles established by CAUCHY, who has shown that in any system of molecules affected with internal tensions, there is at each point a system of three orthogonal planes, corresponding with the three principal planes of the ellipsoid of tension, whose centre is situated at that point. These orthogonal planes further possess the property, that the internal pressures are perpendicular to them, and that one of them is the plane of maximum, and another the plane of minimum tension.

3. *Joint Planes.*

A joint plane is a surface of division in a rock, often remarkably smooth and clean cut, without the slickensides so often seen in faults, rarely accompanied by dislocation of the divided beds, and generally open from $\frac{1}{4}$ inch to 3 or 4 inches. A well-marked joint plane presents so striking a resemblance to the plane surface produced by crystallization, that this class of divisional planes in rocks has always been confidently appealed to by the advocates of the polar or crystalline theory of rock structure. In some cases I have no doubt that this resemblance is not imaginary, as for example in rock-masses of igneous origin, such as granites composed of uniform proportions of quartz, felspar, and mica, or hornblende. Such a rock-mass is truly a definite chemical compound, as much so as any mineral on a small scale, and therefore it is not surprising that it should sometimes present joints and planes intersecting at fixed angles, and characterized by all the properties of true crystalline faces. Such cases have come under my own observation, but not in sufficient numbers to entitle me to state any definite law, although I think much might be accomplished by systematic observations directed specially to this point. However this may be, there can be little doubt that the joints observed in a coarse conglomerate cannot be considered due to crystallization, which can scarcely be supposed to have acted upon a shingle formed of chance stones lying upon the beach of the Old Red Sandstone seas.

The joint surfaces in the conglomerate of Waterford are beautifully perfect, generally open 1 to 4 inches, nearly vertical, and when observed in the sea cliffs, giving rise to an almost columnar structure, in consequence of the sea having washed out huge rectangular prisms from the cliffs; these prismatic cavities and prominences being invariably bounded on two opposite sides by joint surfaces, and on the other two faces by the

cleavage surfaces which will presently be described. A fine example of this is shown in the Conglomerate Cliffs, eastward from Portally Head towards Oonarontia and Red Head: in this district the bedding is completely masked by the nearly vertical planes of joint and cleavage surfaces, which give a rudely prismatic and columnar appearance to the cliffs. Near Swiny Head this structure is remarkably well developed, and has produced a singular effect: one of the rude columns formed by the joint and cleavage surfaces has fallen partially forward, and presents an appearance, especially when seen from the sea, which resembles some of the old stone crosses found in many parts of Ireland.

One of the most striking circumstances connected with the joint surfaces in the conglomerate, is the fact that the large quartz pebbles, often 5 inches diameter, are cut clean across as if with a knife, forming a plane rigorously parallel to the general plane of the joint. The same remarkable fact is constantly observed in the joint surfaces of the carboniferous limestone all through Ireland; in which I have frequently observed a fossil cut in two by the joint plane, half being imbedded in each portion of the divided rock, and fitting accurately to each other when joined. In the cleavage planes the same circumstance is of universal occurrence all through the conglomerate of Waterford. According to my idea of the mechanical origin of these various planes, the cleavage surfaces are perpendicular to the lines of maximum force, and the joint surfaces perpendicular to the lines of minimum force, or maximum force of *shrinkage*, if I may use a barbarous word. The cleavage structure appears to have been first developed in the rock, and the jointed structure subsequently added by the shrinking of the rock-mass, consequent upon evaporation and drying. This shrinking and contraction of the mass would naturally show itself in planes perpendicular to the lines of minimum compression. That the whole rock-mass was pliant, and probably even soft, at the time the elevating forces were applied, appears from the distortion of fossil shells in shale beds of nearly the same age in the west of the County of Waterford, and all through the south of the County of Cork.

At first sight it might appear that the splitting of the hard quartz pebbles by the joint and cleavage planes was inconsistent with the supposition that the rock-mass was in a yielding condition at the time of the application of the forces, as it seems to indicate that these pebbles were held fast, as in a vice, by the hard matrix in which they were imbedded while the faces that split them were in action. I think, however, that independently of the conclusive argument derived from the distortion of the fossils, it is not difficult to understand how a pliant or yielding condition of the mass may have been a necessary condition for the development of this structure. Let us suppose the clay, sand, and mud of some landslip, soft, tough, and yielding, with its imbedded boulders and pebbles to represent the Old Red Sandstone conglomerate, acted on by external forces of compression, and by its own weight; at each point of the mass we shall have a plane of maximum pressure, and one of minimum pressure at right angles to it; and let us suppose a plane of maximum pressure to pass through several boulders or pebbles, which are unyielding substances imbedded in a viscous paste which presses them vari-

ously in different directions, but with a decided maximum in one particular direction. The effect of this pressure will be to cause relative motion among the particles of the paste, flattening them in a direction perpendicular to the line of force, and so causing cleavage structure, in the manner so admirably illustrated by Mr. SORBY's experiment on pipeclay and scales of iron, and by Mr. TYNDALL's experiment on wax. In the meantime the solid pebbles have not yielded sensibly, but show the effect of the enormous pressure they have been subjected to, by developing internally a *latent* cleaved structure, predisposing them to split most readily along planes perpendicular to the line of maximum force. In this manner I would account for the splitting of the quartz pebbles in the planes of cleavage; while, in the case of the joint planes which were formed subsequently, I conceive that the rock was consolidated, and the quartz pebbles held fast in their now hardened paste, while the shrinking took place perpendicular to the planes of minimum tension.

This mode of viewing the subject is confirmed by the fact, that in cleaved limestone districts, the distorted fossils are divided by the joints in well-cut planes, showing that the rock was consolidated when the joints were formed, although the distortion of the fossil proves that the rock was soft when the cleavage took place.

4. *Cleavage Planes.*

My attention was originally directed to the study of the physical geology of the red sandstone conglomerate of Waterford by the observation of two circumstances; the first of these was the rectangular prismatic appearance of the conglomerate cliffs already described; and the second was the detection of an inner structure of a peculiar character, which enabled me readily to distinguish the cleavage from the joint planes. I found that the coarse conglomerate had in many places acquired a platy or flaggy structure, the thickness of each plate varying from $\frac{1}{4}$th of an inch to 4 inches, the flat sides of the plate being perfect planes, cutting through the quartz pebbles in the most beautiful manner, and unaccompanied by any dislocation whatsoever. The moment I observed this peculiar structure in the conglomerate, I felt that I had found the key to the explanation of the physical structure of the whole district. I had before noticed the flaggy appearance assumed by the cleaved limestone of Cork and Kenmare, and the singular platy structure of many of the quartz rocks and grits of West Galway, and had referred them to incipient cleavage, rendered imperfect by coarseness of texture or want of viscosity; the possession of which latter quality appears to be the principal cause of the more perfect cleavage observed in slates and mud rocks in general; but I had never thought of finding cleavage in a coarse conglomerate. Having discovered the appearance of the cleavage proper to so coarse and heterogeneous a rock, I instantly determined to investigate the physical structure of the whole district with reference to this question. I determined with care the bearings and dips of 345 joint and cleavage planes along the coast, from Creadan Head to Brownstown Head and Rinishark, including about thirty observations inland made in quarries. In no case did I record an

observation without observing at least 20 square feet of the plane, and in many cases the surface exposed amounted to several hundred feet; and I may add, that I have not omitted a single observation made by me from the discussion contained in the following Tables.

Before proceeding to the discussion of the observations, I shall give my reasons for considering the planes of the flaggy structure observed by me, to be perpendicular to the lines of maximum force. I had already found in the distorted fossils of West Waterford conclusive arguments in favour of the view put forward by Mr. SHARPE, that the planes of cleavage were perpendicular to the line of maximum force; and before concluding that the platy or flaggy structure of the conglomerate was true cleavage, I was bound to show that its planes were perpendicular to the lines of greatest force. In the absence of fossils this could not be proved in the usual manner; but the following facts, ascertained by me, leave little doubt upon this important point.

Soon after I had first observed the flaggy structure of the cleavage planes of the conglomerate, I found that this structure was confined to planes having the general direction of the system (A), already noticed in speaking of faults, although it was occasionally observed in planes parallel to the system (A′). I never observed the flaggy structure in the systems C or C′; now, as the line of greatest force in a system of elevated beds must lie in the vertical plane, or nearly so, which contains the direction of the dip of the beds, and as the strike of the beds is intermediate between the systems A and A′, it is evident that we have a close approximation to SHARPE's law; and, on the hypothesis already advanced, of two systems of elevating forces, perpendicular to A and A′ respectively, we have an exact conformity to this law.

I only found one locality in the whole district in which the cleaved flaggy structure had any other direction than either A or A′, and in this locality the deviation from the usual direction of cleavage constitutes a powerful argument in favour of the assertion, that the cleavage structure is perpendicular, or nearly so, to the line of maximum pressure.

A little north of Brownstown Head, on the side of Tramore Bay, near a place called Portoonaka Beg, and close to the Ordnance Levelling Mark No. 1, 1841, the rocks are beautifully cleaved with the peculiar flaggy or platy structure already so often described. The cleavage planes have a bearing of N. 12° W., and a dip 77° E. This plane corresponds with the system C, which ought to be a joint and not a cleavage plane; but it so happens, that in this locality there is considerable local contortion in the bedding of the conglomerate and thin shales; and throughout the entire area, in which the flaggy cleavage had this abnormal direction, I found the strike of the beds to have an azimuth or bearing within a few degrees of that of the cleavage. The bearing of the beds, in fact, ranges from N. 5° W. to N. 33° W., dip 10° N. Thus this apparent exception to the first mechanical law of cleavage turns out, on examination, to be a remarkable confirmation of it. I should add, that the flaggy structure at Portoonaka Beg divided the rock with great regularity into plates of 4 or 5 inches in thickness*.

* My attention was directed to this exception to the general direction of the flaggy cleavage by the

5. *Observations Tabulated.*

In the following Tables I have given the bearing and dip of every plane observed, and arranged them according to their geometrical grouping, taking the bearing of the plane as my standard of comparison.

I have also separated the planes east of Red Head from those west of Red Head, as this headland is the geological centre of elevation of the whole district, as I showed in the section on Faults.

TABLE I.

Joint Planes and Cleavage Surfaces, from Red Head Eastward to Creadan Head.

A. North of East.		A′. North of East.		C. West of North.		C′. West of North.	
Flat Rocks.		Flat Rocks.		Flat Rocks.		Flat Rocks.	
Bearing.	Dip.	Bearing.	Dip.	Bearing.	Dip.	Bearing.	Dip.
E. 10° N.	77° S.	E. 35° N.	88° S.	N. 10° W.	86° W.	N. 45° W.	74° E.
		— 33 —	88 —	— 10 —	80 —		
		— 27 —	72 N.				
		— 30 —	70 —				
Shanooan.		Shanooan.		Shanooan.		Shanooan.	
E. 17 N.	87 S.	E. 30 N.	75 S.	N. 15 W.	77 W.	N. 45 W.	75 W.
— 17 —	87 —	— 25 —	77 —			— 23 —	83 —
— 17 —	66 N.	— 26 —	82 —			— 20 —	90
— 10 —	76 —	— 20 —	84 —				
		— 20 —	63 N.				
		— 30 —	50 —				
		— 30 —	65 —				
		— 25 —	76 —				
		— 30 —	67 —				
		— 25 —	54 —				
		— 35 —	57 —				
Quarries.		Quarries.		Quarries.		Quarries.	
E. 10 N.	80 N.	E. 20 N.	72 N.	N. 7 W.	84 E.	N. 35 W.	67 W.
— 0 —	82 —	— 40 —	75 —	— 13 —	85 —		
— 0 —	87 —	— 35 —	90	— 17 —	82 W.		
— 0 —	83 —	— 35 —	70 S.				
— 0 —	86 —						
— 19 —	74 —						
— 5 —	85 —						
E. 8 S.	85 —						
— 5 N.	85 S.						
Harbour.		Harbour.				Harbour.	
E. 10 N.	90	E. 40 N.	90			N. 30 W.	85 W.
— 0 —	90	— 25 —	90			— 35 —	90
— 0 —		— 35 —	90				
— 0 —		— 35 —	75 S.				
— 15 —	90	— 40 —	80 N.				
		— 35 —	80 S.				
		— 25 —	65 N.				

Rev. Dr. CARSON, Fellow of Trinity College, from whom I received valuable aid in my somewhat laborious survey of the County of Waterford conglomerate.

TABLE I. (continued).

A. North of East.		A′. North of East.		C. West of North.		C′. West of North.	
E. of Harbour.		**E. of Harbour.**		**E. of Harbour.**		**E. of Harbour.**	
Bearing.	Dip.	Bearing.	Dip.	Bearing.	Dip.	Bearing.	Dip.
E. 5° N.	88° S.	E. 35° N.	87° N.	N. 5° W.	87° E.	N. 30° W.	70° W.
— 10 —	85 —	— 30 —	87 —	— 0 —	90	— 35 —	90
— 10 —	85 N.	— 40 —	87 —	— 5 —			
— 10 —	60 —	— 40 —	90	— 5 —	90		
— 5 —	90	— 25 —	90	— 0 —	90		
— 12 —	84 N.	— 28 —	90	— 10 —	90		
— 10 —	90	— 40 —	67 N.	— 10 —	70 E.		
		— 30 —	70 —				
		— 30 —	76 —				
Dunmore.		**Dunmore.**		**Dunmore.**		**Dunmore.**	
E. 0 N.	90	E. 33 N.	90	N. 5 W.	90	N. 25 W.	
		— 35 —	90	— 10 —	90		
		— 35 —	90	— 5 —	90		
		— 25 —	90	— 5 —	90		
		— 40 —	70 N.				
Cathedral Rocks.		**Cathedral Rocks.**		**Cathedral Rocks.**		**Cathedral Rocks.**	
E. 12 N.	85 S.	E. 35 N.	78 S.	N. 8 W.	77 E.	N. 30 W.	85 E.
— 10 —	90	— 35 —	77 —	— 10 —	77 —	— 35 —	60 —
		— 40 —	80 —	— 10 —	90	— 30 —	62 —
		— 35 —	90	— 6 —	90		
		— 36 —		— 5 —	90		
		— 37 —		— 10 —	67 W.		
		— 35 —	90				
		— 35 —	80 S.				
Ardnamult.		**Ardnamult.**		**Ardnamult.**		**Ardnamult.**	
E. 10 N.		E. 35 N.	85 S.	N. 0 W.	90	N. 40 W.	
		— 45 —		— 10 —	90	— 35 —	90
		— 35 —				— 45 —	59 W.
		— 40 —	90			— 35 —	80 —
		— 40 —	90				
		— 35 —	90				
		— 40 —	70 S.				
		— 35 —	90				
		— 35 —	80 N.				
Creadan.		**Creadan.**		**Creadan.**		**Creadan.**	
E. 10 N.	90	E. 45 N.	90			N. 30 W.	90
— 10 —	90	— 30 —	90			— 35 —	90
— 10 —		— 35 —					
— 0 —	90						
251 ÷ 34		1990 ÷ 60		191 ÷ 25		638 ÷ 19	
7° 23′ North of East.		33° 10′ North of East.		7° 38′ West of North.		33° 35′ West of North.	

System A.

The system A contains 34 observations to the east of Red Head; of these

14 planes are vertical.

13 dip North at 80° average.

7 dip South at 85° average.

The average bearing of the whole system is 7° 23′ North of East.

This bearing of the cleavage planes is nearly coincident with that of the same system of faults, viz. 7° 30′ North of East.

This may be considered as an east and west system, so far as strike or bearing is concerned; but it is divisible into two systems with respect to dip.

System A′.

The system A′ contains 60 observations; of these

24 planes are vertical.
21 dip North at 71° average.
15 dip South at 79° average.

The average bearing of the whole system is 33° 10′ North of East, which agrees with the bearing of the system of faults called A′, in p. 335, viz. 34° 22′ North of East. This system, A′, is the second east and west system, and the cleavage planes are sometimes found in this direction, though more generally in the direction A. It is to be observed of both these systems, that the planes dip to the north at a smaller angle than to the south.

System C.

This system contains twenty-five observations; of these

14 planes are vertical.
6 dip East at 80° average.
5 dip West at 78° average.

The average bearing of this system of planes, which is conjugate to the system (A), is 7° 38′ West of North.

System C′.

This system, east of Red Head, consists of nineteen observed planes; of which

8 are vertical.
4 dip East at 70° average.
7 dip West at 74° average.

The average bearing of this system is 33° 35′ West of North.

The following Table contains the planes belonging to the conjugate systems A and C, and also A′ and C′, observed westward of Red Head; where the faults are more numerous than to the east, and their downthrows in the opposite direction.

Table II.

Joint Planes and Cleavage Surfaces, from Red Head Westward to Brownstown Head.

A. North of East.		A′. North of East.		C. West of North.		C′. West of North.	
Red Head to Bishop's Cave.		Red Head to Bishop's Cave.		Red Head to Bishop's Cave.		Red Head to Bishop's Cave.	
Bearing.	Dip.	Bearing.	Dip.	Bearing.	Dip.	Bearing.	Dip.
E. 15° N.	83° S.	E. 25° N.	83° S.	N. 10° W.	70° E.	N. 35° W.	53° W.
— 10 —	55 N.	— 25 —	80 —	— 10 —	83 —	— 32 —	66 E.
— 5 —	85 S.	— 25 —	82 —	— 5 —	74 —	— 30 —	86 W.
— 10 —	80 —	— 30 —	80 —	— 5 —	85 —	— 30 —	75 —
— 10 —	74 N.	— 35 —	87 —	— 5 —	90 —	— 25 —	72 E.
— 5 —	65 —	— 35 —	83 —	— 5 —		— 40 —	
— 0 —	70 —	— 35 —	70 N.				
— 5 —	78 —	— 35 —	74 —				
— 5 —	65 —	— 35 —	75 —				
— 5 —	90	— 35 —	90				
		— 35 —	65 N.				
		— 35 —	80 S.				
		— 35 —	76 —				
		— 35 —					
		— 35 —	90				
		— 35 —	80 S.				
		— 35 —	90				
		— 45 —	70 S.				
		— 35 —	80 —				
		— 35 —	80 —				
		— 35 —	90				
		— 20 —	80 S.				
Bishop's Cave to Portally.		Bishop's Cave to Portally.		Bishop's Cave to Portally.		Bishop's Cave to Portally.	
E. 15 N.	84 S.	E. 35 N.	90	N. 5 W.	90	N. 25 W.	87 W.
— 15 —	86 —	— 35 —	90	— 5 —	90	— 40 —	74 E.
— 10 —	85 —	— 30 —	90	— 5 —	90		
— 10 —	87 N.	— 35 —	80 S.	— 5 —	90		
— 10 —	87 —	— 30 —	70 —	— 7 —	86 W.		
— 5 —	68 —	— 35 —	85 —	— 10 —	88 E.		
— 15 —	85 S.	— 40 —	80 —	— 5 —	90		
— 15 —	90	— 30 —	90	— 5 —			
— 10 —	90	— 33 —	85 N.	— 6 —	85 W.		
— 5 —	90	— 33 —	90				
— 15 —	90	— 30 —	90				
— 10 —		— 30 —	85 S.				
Portally to Old Ship's Cove.		Portally to Old Ship's Cove.		Portally to Old Ship's Cove.		Portally to Old Ship's Cove.	
E. 10 N.	85 S.	E. 30 N.	90	N. 0 W.	90	N. 45 W.	90
— 10 —	90	— 30 —	75 N.	— 10 —	90	— 45 —	85 W
— 10 —	90	— 33 —	90	— 15 —	90	— 35 —	75 E.
— 0 —	90	— 35 —	90	— 0 —	90	— 35 —	80 —
— 5 —	90	— 30 —	90			— 30 —	90
— 10 —	90	— 30 —	70 N.			— 30 —	90
— 10 —	90	— 35 —	80 S.			— 40 —	90
— 0 —	60 N.	— 35 —	66 N.			— 40 —	80 E.
— 0 —	70 —	— 30 —				— 35 —	80 —
— 5 —	60 —					— 45 —	90
— 10 —	90						
— 10 —	90						

TABLE II. (continued).

A. North of East.		A′. North of East.		C. West of North.		C′. West of North.	
Old Ship's Cove to Rathmoylan Cove.		Old Ship's Cove to Rathmoylan Cove.		Old Ship's Cove to Rathmoylan Cove.		Old Ship's Cove to Rathmoylan Cove.	
Bearing.	Dip.	Bearing.	Dip.	Bearing.	Dip.	Bearing.	Dip.
E. 10° N.	90°	E. 20° N.	90°	N. 5° W.	90°	N. 35° W.	90°
— 10 —	90	— 20 —	90	— 15 —	90	— 40 —	90
— 15 —	90	— 25 —	90	— 0 —	75 W.	— 40 —	90
— 15 —	70 S.	— 35 —	90			— 40 —	90
		— 35 —	85 N.			— 45 —	86 W.
		— 30 —	90				
		— 40 —					
		— 45 —	90				
		— 35 —	80 N.				
		— 37 —	90				
		— 40 —	87 S.				
		— 35 —	87 N.				
		— 43 —	87 S.				
		— 45 —	87 —				
		— 45 —	85 —				
		— 35 —	55 N.				
		— 35 —	60 —				
Brownstown Head District.		Brownstown Head District.		Brownstown Head District.		Brownstown Head District.	
E. 7 N.	60 N.	E. 35 N.	90	N. 12 W.	77 E.	N. 40 W.	90
— 7 —	60 —	— 33 —	66 N.	— 0	90	— 45 —	90
— 15 —	90	— 33 —	60 —			— 30 —	75 E.
— 5 —	66 N.	— 45 —	80 —			— 33 —	60 W.
— 0 —	75 —	— 33 —	60 —			— 40 —	90
— 3 S.	90	— 35 —	70 —				
— 12 N.	80 N.	— 32 —	90				
— 0 —	60 —	— 32 —	90				
— 0 —	90	— 33 —	90				
		— 45 —	90				
		— 32 —	70 S.				
		— 32 —	70 N.				
		— 35 —	90				
		— 37 —	80 S.				
		— 30 —	80 —				
378÷47		2536÷75		150÷24		1025÷28	
8° 2′ North of East.		33° 48′ North of East.		6° 15′ West of North.		36° 36′ West of North.	

System A.

This system, to the west of Red Head, consists of 47 planes; of which

20 are vertical.
18 dip North at 69° average.
9 dip South at 82° average.

It is to be observed here, as before, that the northern dip of the planes is less than the southern.

The average bearing of system A, west of Red Head, is 8° 2′ North of East.

System A′.

This system is very strongly marked at many places to the west of Red Head. It contains 75 planes observed; of which

30 are vertical.
19 dip North at 71° average.
26 dip South at 81° average.

The northern dip of these planes is also less than the southern.

The average bearing of this system is 33° 48′ North of East, which coincides remarkably well with the bearing of the most important system of faults in the district, viz. A′ = 34° 22′ North of East.

System C.

This system contains 24 observed planes; of which

15 are vertical.
6 dip East at 79° average.
3 dip West at 82° average.

The average bearing of this system is 6° 15′ West of North.

System C′.

This system, west of Red Head, contains 28 observed planes; of which

13 are vertical.
8 dip East at 75° average.
7 dip West at 76° average.

This system bears 36° 36′ West of North; and it is to be observed that the easterly and westerly dips of C and C′ West of Red Head are more nearly equal than the northerly and southerly dips of A and A′, a fact which also appears from the observations East of Red Head.

Besides the planes already recorded, which belong to the conjugate systems A, C, and A′, C′, there were several others, which I have endeavoured to tabulate as follows:—

FRA INST LIBRAR

Exceptional Joint Planes.

(A″.)

Bearing.	Dip.	Locality.
E. 25° S.	80° N.	Creadan Head.
— 30 —		Creadan Head.
— 25 —	80 S.	Creadan Head.
— 25 —	80 —	Creadan Head.
— 30 —	70 —	Creadan Head.
— 20 —	90	Creadan Head.
— 30 —	85 S.	Dunmore Harbour.
— 35 —	90	Dunmore Harbour.
— 35 —	82 N.	Portally, West.
— 37 —	85 —	Portally, West.
— 30 —	85 —	Portally, West.
— 25 —	78 —	Remarkable outlying rock off eastern entrance to Portally Cove.
— 30 —	90	Old Ship's Cove.
— 40 —	90	Beenlea Head.
427÷14		

30° 30′ South of East.

(C″.)

Bearing.	Dip.	Locality.
N. 25° E.	90°	Creadan Head.
— 20 —		Creadan Head.
— 20 —		Creadan Head.
— 25 —		Creadan Head.
— 30 —	77 E.	Old Ship's Cove.
— 30 —	90	Old Ship's Cove.
— 30 —	90	Old Ship's Cove.
— 25 —	82 E.	Swiny Head.
— 40 —	70 —	Rathmoylan Cove.
— 40 —	90	Rathmoylan Cove.
— 40 —	90	Rathmoylan Cove.
— 25 —	68 W.	Quarry inland.
350÷12		

29° 10′ East of North.

(C‴.)

Bearing.	Dip.	Locality.
N. 10° E.	60° E.	Creadan Head.
— 10 —	90	Stone Cross.
— 7 —	77 E.	Rathmoylan Cove.
— 10 —	90	Rathmoylan Cove.
— 10 —	77 E.	Rathmoylan Cove.
— 10 —	90	Rathmoylan Cove.
57÷6		
9° 30′ East of North.		

I find in my note-book one observation of a bearing E. 10° S. made by me at Creadan Cove; it appears to be the solitary representative observed by me of the bearing rectangular and conjugate to that of C‴. Although it is a single observation, I believe it affords evidence (although not strong) of the probable existence in this district of a *fourth* system of forces having acted upon the conglomerate beds.

Total Number of Observations.

A.	A′.	A″.	A‴.	C.	C′.	C″.	C‴.
81	135	14	1	49	47	12	6
Total number of Planes observed = 345							

From the preceding discussion of the planes of structure not belonging to the two principal conjugate systems of the district, I feel little hesitation in coming to the conclusion that there was at least one more system of forces at work, in producing the final structure of the Old Red Sandstone conglomerate of the South East of the County of Waterford.

The bearings of this system are,

30° 30′ South of East,
29° 10′ East of North.

There is also evidence, although not so good, of another conjugate system, bearing 9° or 10° East of North and South of East.

A summary of the four conjugate systems is here added, showing how nearly perpendicular their component bearings are. I consider the first system to have acted first on the district, developing the greater part of the cleavage structure; and that the second system was subsequent to the first, but probably produced by even greater forces; of the third and fourth systems I know nothing beyond their existence; the key to them may possibly be found in other districts.

First Conjugate System.

A.	$62\overset{\circ}{9}\div 81$	$\overset{\circ}{7}\ 46'$ North of East.
C.	$341\div 49$	6 57 West of North.
Angle between Axes from East to North $=89°\ 11'$		

Second Conjugate System.

A′.	$452\overset{\circ}{6}\div 135$	$\overset{\circ}{33}\ 31'$ North of East.
C′.	$1663\div 47$	35 23 West of North.
Angle between Axes from East to North $=91°\ 52'$		

Third Conjugate System.

A″.	$42\overset{\circ}{7}\div 14$	$\overset{\circ}{30}\ 30'$ South of East.
C″.	$350\div 12$	29 10 East of North.
Angle between Axes (North and East) $=91°\ 20'$		

Fourth Conjugate System.

A‴.	One observation.	$1\overset{\circ}{0}\ '$ South of East.
C‴.	$57°\div 6$	9 30 East of North.
Angle between North and East Axes $=90°\ 30'$		

Note added after the reading of the Paper.

Throughout this paper I have assumed the perpendicularity of the cleavage planes to the lines of maximum force. This assumption I have made on evidence quite distinct from the facts mentioned with relation to the perpendicularity of the horizontal traces of the cleavage and joint planes to each other. I believe the proper evidence of the perpendicularity of cleavage to the lines of maximum force must be sought for in fossiliferous slate districts, where the distortion of the fossil enables us to determine the exact position of the line of maximum force, and consequently its relation to the plane of cleavage.

The evidence of fossils is wanting in the conglomerate of the County of Waterford, and we are consequently unable to determine the precise lines of maximum force, except so far as the inclination of the beds gives us information.

Having established by observation the existence of conjugate systems of planes, I have drawn mechanical inferences, founded on the assumption of the perpendicularity of cleavage to the lines of maximum force; and these inferences have not, of course, the same degree of evidence in their favour that the geometrical relations of the cleavage and joint planes have.

In fact, the geometrical relations of these planes are observed facts, while the mechanical inferences have only the probability (in my opinion a high one) of the law assumed on other evidence.

XVIII. *On the Relative Power of Metals and Alloys to conduct Heat.*—Part I. *By* F. Crace Calvert, *Esq., F.C.S., Corr. Mem. Roy. Acad. Turin, Société de Pharmacie, Paris, &c.; and* Richard Johnson, *Esq., F.C.S., &c. Communicated by Professor* Stokes, *Sec. R.S.*

Received February 19,—Read March 25, 1858.

Metals and their alloys being now so extensively employed in arts and manufactures, and for instruments of precision, we have thought that it would be interesting, in a scientific or commercial point of view, if we were to examine their conductibility carefully and completely.

To enable us to determine with accuracy the conducting power of all the ordinary metals, and of seventy of their alloys and thirty of their amalgams, we had to find out a new method of determining the conducting power of metals; for the process followed by M. Despretz could only give results to be relied upon for a few of the best conductors, such as silver, gold, and copper. Further, his process, which consists in having a long and thick bar of metal, so as to allow holes to be drilled, in which mercury and the bulb of a thermometer are inserted, would have required a large quantity of each metal in a state of purity, the labour of obtaining which, even comparatively pure, is well known. Also from the fact of mercury being employed, we should have been unable to ascertain the conducting power of such important alloys as brass and bronzes, and could not have applied the process to amalgams.

The method which we have followed gives such consistent results, that we have not only been able to determine the influence exercised on the conducting power of metals by the addition of 1 or 2 per cent. of another metal, but also to appreciate the difference of conductibility of two alloys made of the same metals, and only differing by a few per cent. in the relative proportions of the metals composing them. At the same time the conditions theoretically required in order to obtain results independent of everything but the nature of the substances, are not very rigorously fulfilled, so that the term conducting power, as used by us, must be understood in a somewhat qualified sense, and as having relation to our method of determining it. We believe, however, that the ratios of the conducting powers, as determined by our method, do not differ from those of the real conducting powers.

Before describing the process followed and examining the results obtained, it is necessary to state that we have made a great number of experiments with the hope of solving the important chemical question, Are alloys simple mixtures of metals, or are they definite compounds? With this view we have operated on a large number of alloys and

amalgams, convinced that if the chemical nature of alloys and amalgams is still enveloped in darkness, it is because they have been prepared with impure or commercial metals, and not made in equivalent quantities. The consequence has been, that as metals have only a slight affinity for each other, and as the definite compounds which they have a tendency to form were mixed with an excess of one of the metals employed, the alloys produced have presented properties which could lead to no information as to their nature. These difficulties have been increased by the fact, that in many alloys, such as those of copper and tin, or copper and zinc, the metals have a tendency, when allowed to cool slowly, to form several crystallizable compounds, differing in their composition in the various parts of the alloys; the less fusible being on the exterior, and those more so in the interior of the mass. The impurities existing in commercial metals are often so large as considerably to modify the properties of their alloys; for we have found in our researches that if 1 per cent. of a metal be added to 99 of another, it alters its conducting power most materially. To avoid these causes of error, we have composed our alloys of pure metals and employed definite proportions.

The apparatus which we used is composed of a deal box (Plate XXVII.), A, 105 millims. in width, 165 millims. in length, and 220 millims. in height; with a cover, and painted white externally and internally. Inside this box are two vulcanized india-rubber square vessels, the sides of which are 15 millims. thick. The larger vessel, B, measures internally 52 millims. on the side and 125 millims. deep, and is capable of containing 336 cub. cent. of water. The smaller vessel, C, is 27 millims. on the side and 125 millims. deep, and has a capacity of 90 cub. cent.

These vessels are painted white and surrounded with wadding; and still further to prevent any radiation of heat, a deal board, D, is placed between the two vessels. So little heat is radiated from the vessel B, when it contains 200 cub. cent. of water at 90°, to the smaller vessel C, containing 50 cub. cent. at 16°, that in a quarter of an hour, the time required for our experiments, the water in the latter vessel did not rise one-tenth of a degree Centigrade. Therefore all sensible radiation and conduction was avoided, and the rise of temperature in this vessel, during the experiment, must have been entirely due to the heat conducted by the square bar of metal (G) used. This bar is 6 centims. long and 1 centim. square, and is so arranged in the experiment, that 1 cub. cent. is in the vessel B, 1 cub. cent. in the vessel C; 3 cub. cent. are covered by the sides of the boxes through which it passes; and the last 1 cub. cent., marked H, is covered with a piece of vulcanized india-rubber tubing, and the whole made secure from any leakage by lining the sides of the holes, through which the bar passes, with a varnish made of caoutchouc dissolved in benzine. This bar is placed 54 millims. from the bottom of B, and 12 millims. from the bottom of C.

When we desire to make an experiment, the vessels are put in water so as to equalize their temperature; they are then carefully wiped and placed in the wooden box, surrounded with wadding, and 50 cub. cent. of water, at the temperature of the room, poured into the vessel C; the two boxes are then covered with vulcanized india-rubber lids, each

perforated with two holes; the vessels are covered with wadding, and the lid of the box shut. Through one of the holes in the vessel C is introduced a very sensitive thermometer, graduated in tenths of a degree; in the other hole is a small whalebone rod, E, having at its extremity a piece of vulcanized rubber to agitate thoroughly the water in the vessel during the experiment, and render it of a uniform temperature. When the water in the vessel C has attained a fixed temperature (which is generally within one degree of that of the room), a thermometer is introduced into the vessel B, and 200 cub. cent. of boiling water poured in by means of a funnel, which communicates with a tube F; the temperature of the liquid falls to 86° or 88°, but is again raised within three minutes to 90°, by a small jet of steam, generated in a flask, the water in which is kept boiling during the whole of the experiment. A few experiments soon enable the operator to keep up a constant temperature of 90° in the vessel B during the quarter of an hour which the experiment requires. Immediately on the boiling water being poured into the vessel B, the operator looks attentively at the scale of the thermometer in vessel C, and as soon as he perceives the column of mercury rising, he carefully marks the second and minute dials of his watch, and makes similar marks fifteen minutes further on. During this time the operator agitates the liquid in vessel C with the agitator E, and every five minutes marks down the rise of temperature. The water in the vessel B has a uniform temperature, owing to the agitation produced in it by the small jet of steam which arrives almost close to the bottom.

The following figures will show how insignificant was the radiation from the large vessel B, containing 200 cub. cent. of water at 90° C., to the smaller vessel C, containing 50 cub. cent. of water at natural temperature, when the two vessels were not connected by a metallic bar, though placed in their usual position in the apparatus, for in fifteen minutes the temperature of the water in the smaller vessel C only increased 0·05 of a degree, and in half an hour only 0°·7.

	Temperature of the water in the vessel C.
	°
	17·20
After 15 minutes	17·25
After 30 minutes	17·90

Therefore the entire increase of temperature in the vessel C, in our experiment, must have been due to the heat conducted by the bar.

It was found that it required twenty-four hours before the temperature of the water in the vessels of the apparatus was in equilibrium with that of the surrounding atmosphere, when 200 cub. cent. of boiling water was poured into the vessel B, and the apparatus left to cool. It might be objected that in our experiments we neglected to take into account the heat absorbed by the sides of the vessel C; but we found, from a great number of experiments, that whether we took into consideration, or not, the amount of heat absorbed, it did not affect in any degree the relative conductibility of the metals and their alloys; but it must be borne in mind that it was not the absolute

quantity of heat communicated to the bar in vessel B which was determined in vessel C, but the relative facility of conduction by various metals, all circumstances being the same. The best proofs that we can give of the accuracy of the process are—1st, that the series of alloys which conduct heat in the ratio of the equivalents of the metals composing them would not have shown such a coincidence between the observed and theoretical results if our process had presented any serious defects. 2nd, that we have been able to determine with accuracy the marked influence exercised by the addition of 1 per cent. of a metal to another metal. 3rd, it will be seen further on in the paper, that we have determined with precision, that in copper bars, having different conducting surfaces, the observed result agrees with the calculated one.

The process followed to ascertain the amount of heat absorbed by the vessel C, consisted in putting into the vessel, cooled down to the natural temperature, 50 cub. cent. of water, having the temperature which the water had when the last experiment was completed, and noticing how much heat was absorbed from the water during the quarter hour. For example—

	Mean conductibility.	Mean absorption.	Total.
Zinc cast vertically . . .	20·03	8·80	28·83
Antimony cast vertically .	6·12	2·50	8·62

but as 20·03 : 6·12 :: 28·83 : x=8·80, the relative conducting power of antimony.

Therefore it is quite clear that the addition of the heat absorbed by the vessel C, to the heat of the water in the same, would have complicated our results without any advantage.

We shall only give two examples here to show how very regularly the apparatus works, and how accurately it indicates the different degrees of conducting power of two metals. The increase of temperature, in the successive five minutes, is in the same ratio whether the conductors be good or bad.

Name of the metals.	Temperature of the room.	Temperature of the 50 cub. cent. of water before beginning.	Temperature of the 50 cub. cent. of water after each 5 minutes.			Constant temperature of the 200 cub. cent. of water.	Conductibility found.	Mean.
Pure Copper...	20°	21°	34°·4	42°·7	48°·0	90°	27·0	27·05
	20	20	33·6	41·8	47·1	90	27·1	
Lead	18	18·2	22·0	25·1	27·4	90	9·2	9·17
	18	18·3	22·1	25·0	27·45	90	9·15	

In fact, it is owing to the facility of appreciating within two-tenths of a degree, in two successive essays, the conducting power of a metal or alloy, that we have been able to determine the precise conducting power of so large a number of alloys and amalgams, and even these researches have required more than a year's constant labour and attention.

The metals which we used were purified by the following processes:—

Gold.—About 140 grammes of nearly pure gold were dissolved in aqua regia, and the liquid evaporated to dryness. The residue was dissolved and filtered, and to the filtrate

a solution of protosulphate of iron was added. The gold thus precipitated was washed with hydrochloric acid, and fused with a little borax and nitre.

Silver.—Pure chloride was reduced by fusing with pure carbonate of potash.

Copper was obtained by reducing pure oxide of copper by a current of pure hydrogen, or by depositing it from a solution of pure salt at a pole of a galvanic battery.

Tin.—Well-crystallized protochloride of tin was recrystallized, and when quite pure, was reduced by being fused with a mixture of bicarbonate of soda and lamp-black.

Bismuth.—Pulverized bismuth was dissolved in strong nitric acid, the liquor filtered through asbestos, and mixed with twenty times its bulk of water. The subnitrate thus obtained was washed, dried, and reduced with lamp-black.

Antimony.—This metal was pulverized and fused with a mixture of pure nitrate and carbonate of soda; the antimoniate of soda so produced was washed with boiling water until the filtrate was no longer alkaline. The insoluble mass was dried and reduced with lamp-black.

Lead.—Nitrate of lead was recrystallized, and when pure, the salt was dried and calcined. The oxide of lead so prepared was reduced by lamp-black.

Zinc.—Vieille Montagne zinc was redistilled twice.

Cadmium.—This metal was obtained pure by dissolving in hydrochloric acid, and passing sulphuretted hydrogen into the liquor. The sulphuret of cadmium was well washed with a solution of sulphuretted hydrogen and dissolved in hydrochloric acid; carbonate of ammonia was added, and the precipitate was washed, dried, mixed with lamp-black, and the cadmium distilled.

The platinum, aluminium, iron and sodium which we used, were only commercially pure.

As the determination of the power of metals to conduct is of great importance, we shall give here a detailed record of the results obtained:—

Name of the metals.	Temperature of the 50 cub. cent. of water before beginning.	Temperature of the 50 cub. cent. after 15 minutes.	Conductibility found.	Mean.	Conductibility. Silver = 1000.
Silver $\frac{1000}{1000}$	19°·8 19·7	51°·6 51·7	31·8 32·0	31·9	1000
Gold $\frac{1000}{1000}$	14 13·6	45·4 44·8	31·40 31·20	31·30	981
Gold $\frac{999}{1000}$	20·3 20·3 20·0	47·3 47·0 46·7	27·0 26·7 26·7	26·80	840
Copper (rolled)	19·5 20·0 21·0 20·5	46·3 47·1 48·0 47·45	26·8 27·1 27·0 26·95	26·95	845
Copper (cast)	21·30 21·45	47·2 47·3	25·90 25·83	25·87	811
Mercury	15·0 16·6	36·7 38·1	21·7 21·5	21·60	677
Aluminium	18·2 17·7	39·3 39·0	21·1 21·3	21·20	665

TABLE (continued).

Name of the metals.	Temperature of the 50 cub. cent. of water before beginning.	Temperature of the 50 cub. cent. after 15 minutes.	Conductibility found.	Mean.	Conductibility. Silver = 1000.
Zinc (rolled)	18°·4 19·9 18·5	39°·0 40·2 38·9	20·6 20·3 20·4	20·45	641
Zinc (cast vertically)	19·6 19·2 14·0	39·8 39·1 35·0	20·2 19·9 20·0	20·03	628
Zinc (cast horizontally)	20·6 20·8	40·0 40·2	19·4 19·4	19·40	608
Cadmium	18·0 16·5	36·5 34·8	18·5 18·3	18·40	577
Malleable iron	18·70 19·05	32·6 33·0	13·9 13·90	13·92	436
Tin	20·5 21·2	34·0 34·6	13·55 13·4	13·45	422
Steel	15·2 15·5	27·8 28·2	12·6 12·7	12·65	397
Platinum	15 14	27·1 26·2	12·1 12·2	12·15	380
Sodium	14·2 14·1	25·9 25·7	11·7 11·6	11·65	365
Cast iron	14·9 15·6	26·4 27·0	11·50 11·40	11·45	359
Lead	20·5 18·3	29·70 27·45	9·20 9·15	9·17	287
Antimony (cast horizontally)	14·6 14·3	21·5 21·1	6·9 6·8	6·85	215
Antimony (cast vertically)	19·2 18·9	25·30 25·05	6·10 6·15	6·12	192
Bismuth	19·0 18·3	21·00 20·20	2·00 1·90	1·95	61

From the details given in describing the apparatus used in our experiments and the methods followed, it will be easy to perceive that for the solid metals we always employed square bars, 1 c. m. square and 6 c. m. long. These bars were always cast of a larger size than required, and were filed down to the exact dimensions. For mercury and sodium we were obliged to have recourse to other methods of operating. We employed a very thin sheet-iron box, the internal dimensions of which were exactly those of the square metallic bars which we usually employed. To admit the mercury, there was in the middle of one of the longitudinal surfaces, a small hole 4 millims. in diameter, and when full of mercury the hole was stopped with a little thick caoutchouc varnish. The box was then weighed, by which it was easy to ascertain if it was quite full. It was then introduced into the two vulcanized india-rubber boxes, and the conducting power of the mercury and box determined. By subtracting the special conducting power of the box (which had previously been ascertained) from the total conducting power of the box and mercury, the difference was the conducting power of the mercury as given above. We operated in the same way with sodium, with this difference, that we melted the sodium under benzine, and whilst fluid filled the box with it. Of course we cannot pretend that the figures which we give in these two instances repre-

sent their exact conducting power, but they are at all events very near the truth. We endeavoured to ascertain the conducting power of potassium in the same way, but failed, owing to the tendency which potassium has to granulate when melted under benzine.

We think it our duty to state, that we are aware of the respective works of M. LANGBERG and of MM. WIEDEMANN and FRANZ, but that we have not followed their thermo-electrical process, as we deemed our method capable of giving more direct and reliable results. We have, however, great pleasure in confirming their results with reference to the superior conducting power of silver to that of gold, though the order of conductibility of the other metals as determined by our process is different from theirs.

In determining the conducting power of metals great attention must be paid to their physical state, as their conductibility is modified by their molecular condition.

Influence of Molecular Condition.

We found that the conducting power of several metals was different when they were rolled out into bars, or when cast. Thus, for example,—

	Conductibility found.	Conductibility. Silver = 1000.
Rolled copper . . .	26·95	845
Cast copper	25·87	811.

It is probable that the reason why rolled metal conducts heat better than the same metal when simply cast, is that the molecules composing the rolled metal are in closer contact than those composing the cast metal, owing to the process of rolling; and it is worthy of observation, that this view agrees with Mr. J. P. JOULE's theory, that heat travels in bodies by the vibration of matter, and not by the fluid called caloric, travelling between the interstices of the molecules.

Influence of Crystallization.

The influence of the molecular arrangement is clearly illustrated in the following examples, where it is seen that the conducting power of zinc, antimony, and bismuth is modified according to the axes of crystallization. Thus the conducting power of zinc is different if the sample for experiment is cast horizontally or vertically; for example,

	Conductibility found.	Conductibility. Silver = 1000.
Zinc cast vertically . .	20·03	628
Zinc cast horizontally .	19·40	608

If these two square bars be broken and examined, they present a very great difference.

The one cast vertically has four axes of crystallization, all starting from the centre and proceeding towards each angle of the bar, as shown in Plate XXVII. The one cast horizontally has one centre line or axis of crystallization, which divides the square bar into three parts.

The results obtained with antimony are the following:—

	Conductibility found.	Conductibility. Silver=1000.
Antimony cast vertically . .	6·12	192
Antimony cast horizontally . .	6·85	215

We shall refer to the extraordinary influence exercised by crystallization on conduction of heat when we examine some of the alloys.

Influence of small amounts of impurities on the Conducting Power of Metals.

We have thought that it would be useful to ascertain the influence which 1 per cent. of a metal exercises when added to another, and these are the curious results obtained with gold and silver:—

	Found.	Conductibility. Silver = 1000.
Pure gold	31·31	981
Gold with 1 per cent. of silver . . .	26·80	840

Therefore the addition of 1 per cent. of silver, the best conductor, to gold, diminishes its conducting power nearly 20 per cent.

We have observed much more marked examples of the diminution of conductibility of a metal by the addition of 1 per cent. of another metal, for example, whilst the conducting power of pure mercury is 21·60, it is only 13·15 when amalgamated with 1·25 per cent. of tin. Professor W. THOMSON having lately discovered that a small quantity of various metals added to copper greatly modifies the conduction of electricity by this metal, we deemed it advisable to try if the conduction of heat by copper would also be altered if we were to alloy it with 1 per cent. of various other metals. We were fortunate enough to obtain results which coincide with his, namely, that some metals increase the conduction of heat by copper, whilst others diminish it.

We have also examined the influence which carbon exercises on the conductibility of iron, and we hope that the results observed will prove useful in a commercial point of view; for as seen by the figures obtained, the difference is about equal to 18 per cent. The following are the results:—

	Found.	Conductibility. Silver = 1000.
Malleable iron *	13·92	436
Steel	12·65	397
Cast iron	11·45	359

* The iron was manufactured from the same cast iron as that used in this experiment, and both were identical to those used by Mr. JOULE in his thermo-electrical experiments. Their composition was as follows:—

	Analysis of cast iron.	Wrought iron.
Carbon	2·275	0·296
Silicium	2·720	0·120
Phosphorus	0·645	0·139
Sulphur	0·301	0·184
Manganese and aluminium .	traces	
Iron	94·059	99·311
	100·000	100·000

We also thought that it would be interesting to ascertain what would be the influence of another non-metallic substance on a metal, and we accordingly made the following series:—

	Found.	Mean.	Conductibility. Silver = 1000.
Cast copper	.....	25·87	811
Copper with 1 per cent. of arsenic ...	18·1 18·3	18·20	570
Copper with 0·5 per cent. of arsenic	21·3 21·4	21·35	669
Copper with 0·25 per cent. of arsenic	24·7 24·5	24·60	771

These results confirm the influence of a non-metallic body on the conductibility of a metal. It is interesting to observe that the influence of arsenic on the conduction of heat on copper is in ratio with the increased quantity of arsenic.

We have also examined a great number of alloys with the hope of throwing some light on their chemical composition, and we trust that the facts which we are about to describe will not only tend to illustrate this point, but will also be of interest from the new and various results observed.

We have also made a great variety of experiments with the view of ascertaining if there be a general law in connexion with the conduction of heat by alloys, and although we could not trace any general rule, still we observed several useful facts.

The conduction of heat by alloys may be considered under three general heads:—

1. Alloys which conduct heat in ratio with the relative equivalents of the metals composing them.

2. Alloys in which there is an excess of equivalents of the worse conducting metal over the number of equivalents of the better conductor, such as alloys composed of 1Cu and 2Sn; 1Cu and 3Sn; 1Cu and 4Sn, &c., and which present the curious and unexpected rule that they conduct heat as if they did not contain a particle of the better conductor; the conducting power of such alloys being the same as if the square bar which we were examining was entirely composed of the worse conducting metal. A not less remarkable fact is that the alloys of a series such as those of 2 equivalents of bismuth and 1 of lead, 3Bi and 1Pb, 4Bi and 1Pb, 5Bi and 1Pb, all conduct the same, viz. about 1·9, the various increasing quantities of lead exercising no influence on the conductibility of the alloys. The results obtained with this class of alloys are most important to engineers; for it will be seen in the case of the alloys of brass and bronze, that no increase is gained in the conductibility of an alloy by increasing the quantity of a good conductor; nay, in many cases it would be a decided loss, unless a sufficient quantity of the better conducting metal be employed to bring the alloy under the third head.

3. Alloys composed of the same metals as the last class, but in which the number of equivalents of the better conducting metal is greater than the number of equivalents of

the worse conductor; for example, alloys composed of 1Sn 2Cu; 1Sn 3Cu; 1Sn 4Cu: in this case each alloy has its own arbitrary conducting power; the conductibility of such an alloy gradually increases and tends towards the conducting power of the better conductor of the two metals composing the alloy.

Before describing the experiments which relate to these three classes of alloys, we deem it advisable to state, that from the numerous assays which we have made, we are led to believe that the conduction of heat by alloys is greatly modified by the crystalline system to which each of the metals composing them belongs, or by the peculiar crystalline form of its own crystals; for we have observed that some of the crystallized alloys of copper and tin, and copper and zinc, have a special conducting power of their own; for example,—

		Found.	Calculated.	Silver = 1000.	
				Found.	Calculated.
Tin ... 1 equivalent ...	32·21	15·75	21·37	494	670
Copper, 3 equivalents ...	61·79				
	100·00				
Tin ... 1 equivalent ...	31·73	4·96	21·88	155	686
Copper, 4 equivalents ...	68·27				
	100·00				

Whilst the alloys which present little or no crystallization have a conductivity which is in ratio to the equivalent quantities of the metals composing them; for example,—

		Found.	Calculated.	Silver = 1000.	
				Found.	Calculated.
Lead ... 1 equivalent ...	36·99	11·96	11·86	375	372
Tin ... 3 equivalents ...	63·01				
	100·00				
Lead ... 1 equivalent ...	30·56	12·17	12·14	381	381
Tin ... 4 equivalents ...	69·44				
	100·00				

The method which we have followed to calculate the theoretical conducting power of our alloys is the following:—

Multiply the per-centage quantity of each metal by the respective conducting power of that metal, add the results together and divide by 100; for example, in the alloy Pb 3Sn,

$$\begin{array}{rl} \text{Pb } 36{\cdot}99 \times 9{\cdot}17 = & 339{\cdot}19 \\ \text{3Sn } 63{\cdot}01 \times 13{\cdot}45 & 847{\cdot}48 \\ \hline 100) & 1186{\cdot}67 \\ \hline & 11{\cdot}86 \end{array}$$

the theoretical conducting power of the alloy.

We have also taken care always to cool the alloys rapidly, so as to render their mass

of a more uniform composition, and prevent, especially in copper and tin alloys, the formation of various crystalline compounds having different compositions.

The description of the physical appearance of these alloys will be given in a paper on their hardness.

The first class of alloys which we shall describe, are those which conduct heat in the ratio of the conductibility of the metals composing them. This class is represented by the alloys of tin and lead, and tin and zinc.

Formula of the alloys and per-centage.	Found (Mean).	Calculated.	Silver = 1000.	
			Found.	Calculated.
5Sn = 73·97 1Pb = 26·03	12·28	12·30	385	386
4Sn = 69·44 1Pb = 30·56	12·17	12·14	381	381
3Sn = 63·01 1Pb = 36·99	11·96	11·86	375	372
2Sn = 53·18 1Pb = 46·82	11·16	11·16	350	350
1Sn = 36·22 1Pb = 63·78	10·52	10·72	230	236
1Sn = 22·11 2Pb = 77·89	10·00	10·11	313	317
1Sn = 15·91 3Pb = 84·09	9·91	9·85	311	309
1Sn = 12·44 4Pb = 87·56	9·60	9·69	301	304
1Sn = 10·20 5Pb = 89·80	9·55	9·60	299	301

Tin and Zinc.

Formula of the alloys, and per-centage.	Temperature of the 50 cub. cent. before beginning.	Temperature of the 50 cub. cent. after 15 minutes, from 5 to 5 minutes.				Conductibility found.	Mean.	Calculated.	Silver = 1000.	
									Found.	Calculated.
5Zn = 73·43	17°·0	24°·9	30°·3	34°·2		17·2	17·25	18·25	541	572
1Sn = 26·57	17·0	24·7	30·2	34·3		17·3				
4Zn = 68·86	16·4	24·3	30·5	34·7		18·3	18·3	17·99	574	564
1Sn = 31·14	16·0	24·1	30·0	34·3		18·3				
3Zn = 62·43	17·6	25·3	30·5	34·4		16·8	16·9	17·57	530	551
1Sn = 37·57	16·7	24·5	29·9	33·7		17·0				
2Zn = 53·11	18·5	26·4	31·5	35·2		16·7	16·65	16·95	522	532
1Sn = 46·89	17·5	24·9	30·3	34·1		16·6				
1Zn = 35·61	18·1	25·5	30·5	34·1		16·0	16·00	15·80	501	495
1Sn = 64·39	17·4	24·6	29·8	33·4		16·0				
1Zn = 21·65	17·1	23 8	28·7	32·3		15·2	15·15	14·90	475	467
2Sn = 78·35	16·6	23·3	28·2	21·7		15·1				
1Zn = 15·55	17·5	24·3	28·9	32·2		14·7	14·6	14·39	458	451
3Sn = 84·45	17·6	24·4	28·9	32·1		14·5				
1Zn = 12·14	17·3	23·8	28·7	32·0		14·7	14·6	14·25	457	447
4Sn = 87·86	17·5	23·8	28·8	32·0		14·5				
1Zn = 9·95	17·1	23·6	28·4	31·7		14·6	14·55	14·10	456	442
5Sn = 90·05	17·0	23·4	28·2	31·5		14·5				

The above two series of alloys are the only ones which conducted heat as above stated; and from experiments which will be described further on, we believe that the metals composing these alloys are simply mixed and not combined together.

Alloys containing an excess of the worse conducting Metal.

The study of this class of alloys being most interesting, we have made many experiments in order to discover why the presence of one metal completely annihilates the conducting power of the other, especially when the latter is the better conductor of the two.

The following series will illustrate the above statement.

Lead and Antimony.

Formula of the alloys and per-centage.	Found (Mean).	Calculated.	Silver = 1000.	
			Found.	Calculated.
1Pb = 61·61 1Sb = 38·39	6·05	8·00	190	251
1Pb = 47·60 2Sb = 52·40	5·90	7·57	185	237
1Pb = 34·86 3Sb = 65·14	5·85	7·18	184	225
1Pb = 28·63 4Sb = 71·37	5·70	6·99	179	219
1Pb = 24·30 5Sb = 75·70	5·70	6·85	179	215

It will be perceived, on looking over the results obtained, that all these alloys conduct heat almost as if the square bars examined were composed of pure antimony, the conducting power of which is 6·12; for if lead, which has a conducting power of 9·17, had influenced the passage of heat through the bars, the conducting power of the alloys would have been much higher, as shown by the column of theoretical conductibility.

The same results were obtained with the following series composed of bismuth and antimony:—

Antimony and Bismuth.

Formula of the alloys and per-centage.	Found (Mean).	Calculated.	Silver = 1000.	
			Found.	Calculated.
1Sb = 37·74 1Bi = 62·26	1·97	3·52	62	110
1Sb = 23·26 2Bi = 76·74	1·87	2·92	59	91
1Sb = 16·81 3Bi = 83·19	1·90	2·64	59	83
1Sb = 13·17 4Bi = 86·83	1·50	2·47	47	77
1Sb = 10·82 5Bi = 89·18	1·55	2·39	48	75

We now describe the most important series of this class of alloys, namely, that consisting of those composed of tin and copper.

Copper and Tin.

Formula of the alloys and per-centage.	Temperature of the 50 cub. cent. before beginning.	Temperature of the 50 cub. cent. after 15 minutes.	Conductibility found.	Mean.	Calculated.	Silver = 1000.	
						Found.	Calculated.
Cu = 34·98 Sn = 65·02	20°·8 19·8	34°·0 33·1	13·2 13·3	13·25	17·80	415	558
Cu = 21·21 2Sn = 78·79	19·4 19·5	33·2 33·2	13·8 13·7	13·75	16·08	431	504
Cu = 15·21 3Sn = 84·79	19·2 19·45	32·80 32·85	13·6 13·4	13·50	15·33	423	481
Cu = 11·86 4Sn = 88·14	18·9 19·0	31·7 32·1	12·8 13·1	12·95	14·92	406	468
Cu = 9·73 5Sn = 90·27	19·4 19·7	32·0 32·4	12·6 12·7	12·65	14·65	396	459

It is very interesting to observe, that although these alloys contain such different quantities of copper, viz. from 9·73 to 34·98, and this of a good conductor of heat, still no influence is exercised by it on the conductibility of the alloys, for they all give the same results as if the square bar experimented upon were composed of pure tin. Another fact, which increases the importance of the bronze alloys, is the difference which they present in their conductibility when they contain an excess of copper, not only with regard to the above series, but also between each alloy, all of which have a conducting power of their own.

Copper and Tin.

Formula of the alloys and per-centage.	Temperature of the 50 cub. cent. before beginning.	Temperature of the 50 cub. cent. after 15 minutes.	Conductibility found.	Mean.	Calculated.	Silver = 1000.	
						Found.	Calculated.
Sn = 38·21 3Cu = 61·79	21° 20·6	36°·7 36·4	15·7 15·8	15·75	21·37	494	670
Sn = 31·73 4Cu = 68·27	18·2 18·0 19·3 18·4	23·1 23·1 24·25 23·30	4·9 5·1 4·95 4·90	4·96	21·88	155	686
Sn = 27·10 5Cu = 72·90	17·7 18·7 17·9	24·2 25·3 24·5	6·5 6·6 6·6	6·6	22·50	207	705

The results obtained with Sn 4Cu were so extraordinary, that the bar first prepared was remelted and cast, from a fear that there might be in the mass some vacant space or hole impeding conduction; but as it yielded the same results when submitted to experiment, we decided to make a new bar, weighing most carefully the metals to be used and also the bar when cast; the loss being only 0·5 per cent., we were satisfied that the bar was sound, and still it gave the same figures as the bar first experimented with;

and therefore we concluded that an alloy of tin and copper containing 68 per cent. of the latter metal, has a conducting power five times less than it should have according to theory. From the above results it is highly probable that these alloys of tin and copper, and especially the three last, are definite chemical compounds; for if they were mixtures, they would conduct heat in ratio to the equivalents of the metals composing them, and would not each have a peculiar and different conductibility. These views are substantiated by experiments which we have made with square bars composed of sectional parts of copper and tin. These bars were made by a very skilful optician of this town, Mr. DANCER, and the parts soldered together with tin solder in so thin a layer, that it did not occupy a space of 0·25 millim. in the five junctions.

The first two bars we employed were of the usual dimensions, and composed of cubes of copper and tin, each 1 cub. cent., arranged in the following order:—

Bar No. 1 (see Plate XXVII.), 2 cubes of tin, 2 cubes of copper and 2 cubes of tin.
Bar No. 2 (see Plate XXVII.), 2 cubes of copper, 2 cubes of tin and 2 cubes of copper.
The results arrived at were—

	Found (Mean).	Calculated.	Silver = 1000.	
			Found.	Calculated.
Bar No. 1	17·25	18·12	541	568
Bar No. 2	18·35	22·23	575	696

Therefore these two bars conduct heat nearly as the theoretical results indicate; the slight difference of 1 or 2 degrees between the obtained and calculated figures being probably due to the influence of the tin solder existing between each cube, and to the cubes not being perfect in all their dimensions. Still, what different results these bars give, as compared with alloys having nearly the same per-centage of tin and copper! for we have

			Obtained.	Calculated.	Silver = 1000.	
					Found.	Calculated.
Bar No. 1. Tin	62·39	Conductibility	17·25	18·12	541	568
Copper...	37·21					
	100·00					
Alloy:— 1 equivalent of Tin.....	65·02	Conductibility	13·25	17·80	415	558
1 equivalent of Copper	34·98					
	100·00					
Bar No. 2. Tin	29·33	Conductibility	18·35	22·23	575	696
Copper...	70·67					
	100·00					
Alloy:— 1 equivalent of Tin	31·73	Conductibility	4·96	21·88	155	686
4 equivalents of Copper	68·27					
	100·00					

These results appear to us perfectly to substantiate our views, viz. that these alloys are definite chemical compounds, and not a mixture of metals; for if they were the latter they would conduct heat as the bars, and would not have a conductibility of their own. We deemed it advisable to have a third bar made, in which the cubes of copper and tin alternated, and these are the results obtained (see Plate XXVII.):—

	Found.	Mean.	Calculated.	Silver = 1000.	
				Found.	Calculated.
Bar No. 3	18·1 18·3	18·2	20·22	570	634

The composition of this bar is intermediate between that of the alloys Sn 2Cu and Sn 3Cu, which contain in 100 parts:—

			Obtained.	Calculated.	Silver = 1000.	
					Found.	Calculated.
1 equivalent of Tin	51·83	Conductibility	13·65	19·87	428	623
2 equivalents of Copper	48·17					
	100·00					
1 equivalent of Tin	38·21	Conductibility	15·75	21·37	494	670
3 equivalents of Copper	61·79					
	100·00					
Whilst the bar is composed of—						
Tin	45·36					
Copper ...	54·64					
	100·00					
And conducts as a mixture, or			18·20	20·22	570	634

Notwithstanding these facts, we were not prepared for the curious results which we obtained with the following bar, composed of two longitudinal bars of tin soldered to two of copper and placed in juxtaposition (see Plate XXVII. bar No. 4); for although it contained in 100 parts the same weight of tin and copper as the last bar, it conducted heat at quite a different rate; in fact, its conductibility was the same as if the bar was entirely composed of pure copper, and did not contain half its bulk of tin.

	Found.	Mean.	Calculated.	Silver = 1000.	
				Found.	Calculated.
Bar No. 4	26·5 26·4	26·45	20·22	829	634

These interesting results were confirmed by having similar bars made of copper and zinc, and copper and lead.

		Found.	Mean.	Calculated.	Silver = 1000.	
					Found.	Calculated.
Bar No. 5.	Copper = 56·12 Zinc = 43·88	26·8 26·9	26·85	23·33	842	731
Bar No. 6.	Copper = 43·42 Lead = 56·58	23·0 23·1	23·05	16·42	723	515

We wished to ascertain if the extent of surface of the copper in contact with the other metal exercised any influence. We therefore had a bar made in which there was the same relative weight of tin and copper, but in which the surface of the two metals in contact was only one half of that of the bar No. 4. This was effected by soldering together one bar of copper, 1 centim. wide and 5 millims. thick, to a similar one of tin (see Plate XXVII. bar No. 7); and although the results leave some doubt whether the surfaces have an action, still the figures are sufficiently different to deserve serious consideration.

	Found.	Mean.	Calculated.	Silver = 1000.	
				Found.	Calculated.
Bar No. 7	24·2	24·15	20·22	757	634
Bar No. 4	24·1	26·45	20·22	829	634

The conductibility of these bars, and especially of Nos. 4 and 6, being equal to that of rolled copper, with which they had been made, we wished to see what would ensue, if bars of the same copper, and having the same diameter or surface as that of the copper in the above bars, were subjected to experiment. These are the results:—

Bar No. 8. Square copper bar of 7 millims. square, or one half the bulk of the bar usually employed.

Found.	Mean.	Calculated.	Silver = 1000.	
			Found.	Calculated.
19·1 19·1	19·1	17·73	599	591

Bar No. 9*. Bar of rolled copper, 5 millims. thick and 1 centim. wide.

Found.	Mean.	Calculated.	Silver = 1000.	
			Found.	Calculated.
19·4 19·3	19·35	18·86	606	591

* The surfaces in the vessels B and C of bar 9 being to our standard bar of copper $5 : 3{\cdot}5 :: 26{\cdot}95 : x = 18{\cdot}86$.

Therefore there cannot remain a doubt that the presence of tin, zinc, or lead in the bars exercise a marked action on the conductibility of the copper; for we have—

1 centim. square bar of rolled copper	26·95
7 millims. square bar of rolled copper	19·12
5 millims. thick, 1 centim. wide } bar of rolled copper	19·35
1 centim. square bar of rolled copper and tin	26·45
1 centim. square bar of rolled copper and zinc . . .	26·85
1 centim. square bar of rolled copper and lead * . . .	23·05

Alloys in which there is an excess of the good Conductor.

Having already described the peculiar properties presented by four of the bronze alloys, viz. those of Sn 2Cu, Sn 3Cu, Sn 4Cu and Sn 5Cu, we should have nothing more to add to them, if we did not wish to illustrate the extraordinary influence which tin exercises on the conductibility of copper, and also to show that when there is a great excess of a good conductor in an alloy, it overcomes the resistance of the bad conductor, and in consequence the conductibility of such alloys increases with the proportion of the good conductor.

	Obtained.	Calculated.	Silver = 1000.	
			Obtained.	Calculated.
Sn = 27·10, 5Cu = 72·90	6·60	22·50	207	705
Sn = 15·68, 10Cu = 84·32	9·80	23·90	307	749
Sn = 11·03, 15Cu = 88·97	12·82	24·50	402	768
Sn = 8·51, 20Cu = 91·49	14·85	24·81	465	778
Sn = 6·83, 25Cu = 93·17	15·15	25·02	475	784

Alloys of Bismuth and Antimony.

These alloys also show a gradually higher degree of conductibility as the number of equivalents of antimony increases in the compound.

	Obtained.	Calculated.	Silver = 1000.	
			Obtained.	Calculated.
Bi = 62·26, Sb = 37·74	1·97	3·52	62	110
Bi = 45·21, 2Sb = 54·79	2·45	4·23	76	132
Bi = 35·48, 3Sb = 64·52	2·55	4·63	80	145
Bi = 29·20, 4Sb = 70·80	3·05	4·90	96	153
Bi = 24·81, 5Sb = 75·19	3·45	5·08	108	159

* A metal having a very low conducting power.

Alloys of Antimony and Lead.

Owing no doubt to the slight difference of the conductibility of these two metals,

Antimony being . . 6·12
Lead . . . . . 9·17

the influence of excess of equivalents of lead over those of antimony is not so striking in this series as in the preceding one. The following are the results observed:—

	Found.	Calculated.	Silver = 1000.	
			Found.	Calculated.
Sb=38·39, 2Pb=61·61	6·05	8·00	190	251
Sb=23·68, 4Pb=76·32	6·50	8·44	204	265
Sb=17·20, 6Pb=82·80	7·05	8·64	221	271
Sb=13·48, 8Pb=86·52	7·00	8·75	219	274
Sb=11·08, 10Pb=88·92	7·35	8·83	230	276

Alloys of Zinc and Copper.

The reason why we have kept these alloys all together, and have not divided them so as to bring them under the last two divisions, is, that they have a tendency to come entirely under the last division. We say a tendency, for they do not offer the distinctive degrees of conductibility that the alloys of copper and tin or bismuth and antimony present; but this may be due to the conducting powers of copper and zinc being within a few degrees of one another,

Cast Copper being . 25·87
Cast Zinc . . . . 20·03.

Conductibility of Copper and Zinc Alloys.

	Obtained.	Calculated.	Silver = 1000.	
			Obtained.	Calculated.
Cu=49·32, Zn=50·68	21·95	22·92	688	718
Cu=32·74, 2Zn=67·26	13·65	21·91	428	687
Cu=24·64, 3Zn=75·36	16·95	21·44	531	672
Cu=19·57, 4Zn=80·43	18·80	21·14	589	663
Cu=16·30, 5Zn=83·70	19·00	20·95	595	657

It is probable that Cu 2Zn and Cu 3Zn are definite compounds, for not only have they a special conducting power of their own far below that of the metals composing them, but also they are perfectly crystallized. The most splendid of all the brass alloys is the alloy CuZn, which is of a beautiful gold colour and crystallizes in prisms, often 3 centims. long. These crystals are also interesting on account of their extraordinary elasticity. It is surprising that so cheap an alloy has not been employed in commerce, for no commercial brass contains more than 30 to 35 per cent. of zinc, whilst the above one contains 50·68 of this metal. The only explanation that we can give of this fact is, that if copper be alloyed with more than 50 per cent. of zinc, the alloys formed do not possess the colour of brass, but become white as zinc, and therefore the manufacturers have never tried to unite these metals in the exact proportions given above. We say exact, for it is remarkable that a variation of a few per cent. in the relative proportions of the two metals no longer yields the beautiful alloy which we have noticed, but only a white and comparatively useless one.

Alloys with excess of Copper.

	Found.	Calculated.	Silver = 1000.	
			Found.	Calculated.
Zn = 33·94 2Cu = 66·06	19·80	23·80	621	748
Zn = 25·52 3Cu = 74·48	20·35	24·37	638	764
Zn = 20·44 4Cu = 79·56	21·25	24·67	666	770
Zn = 17·05 5Cu = 62·95	22·80	24·87	715	780

We also made a bar 1 centim. cub. square of zinc and copper, placing a cube of each metal alternately, as in No. 3 bar of tin and copper, and the result obtained is similar; for we have—

	Found.	Calculated.	Silver = 1000.	
			Found.	Calculated.
Bar 10.....	22·5	23·33	705	731

The facts presented by a bar 1 centim. square, and composed of two longitudinal bars of copper and zinc, have been described under the bar No. 5.

We also thought that it might be useful if we were to analyse the following commercial alloys, and determine their respective conducting powers.

		Found.	Calculated.	Silver = 1000.	
				Found.	Calculated.
"Yellow brass" ...	Cu = 64·0 Zn = 56·0	17·80	22·73	558	712
"Pumps and pipes"	Cu = 80·0 Sn = 5·0 Zn = 7·5 Pb = 7·5	13·60	22·57	426	707
"Mud plugs"	Cu = 80·0 Sn = 10·0 Zn = 10·0	12·60	24·00	394	754
"Large bearings" ...	Cu = 82·05 Sn = 12·82 Zn = 5·13	11·00	23·97	345	751

It is extraordinary to find what a low conducting power these alloys possess; for with the exception of the alloy named "Yellow brass," they do not conduct heat better than wrought and cast iron. This is due to the impurities of the metals employed, and shows the advantage that there will be in substituting for them some of the much cheaper alloys above described.

We hope that the results contained in this paper will prove interesting to the members of the Royal Society, and deserve their approbation.

We shall shortly have the honour to forward Part II. of this paper "On Amalgams."

XIX. *On the Thermo-electric Series.* *By* AUGUSTUS MATTHIESSEN, *Ph.D.* *Communicated by* CHARLES WHEATSTONE, *Esq.*

Received November 20, 1857,—Read January 14, 1858.

BEING enabled by the method described in the Philosophical Magazine (February 1857) to obtain wires of the metals of the alkalies and alkaline earths, I have determined their places, together with most of those of the other metals and some alloys, in the thermo-electric series. The alloys which were experimented with, are those described by ROLLMAN* as giving with other metals stronger thermo-electric currents than those of bismuth or antimony under the same circumstances.

If A, B, C are different metals, and (A, B), (B, C), (C, A) the electromotive powers of thermo-elements formed out of each two of these metals, whose alternate soldering-points are at two different temperatures, then (A, B)+(B, C)+(C, A)=0, and therefore†

$$(A, B)=a-b,$$
$$(B, C)=b-c,$$
$$(C, A)=c-a,$$

where the values of a, b, c not only depend on the two temperatures, but also on the nature of each of the metals A, B, and C. As the "differences" of the same constitute the electromotive powers, the value for any one of these metals may be put =0. If the temperatures of the soldering-points of a thermo-element only vary slightly, the electromotive power may be said to be proportional to the difference of the two temperatures, and under the same conditions the quantities a, b, c are also proportional to the difference of the temperatures, and their ratios to each other therefore independent of the same. If now the value of a second metal relative to the above-named value of the first be taken =1, the values of the others in relation to these can be deduced, and only depend on the nature of each metal. These values I will call the Thermo-electric Numbers of the metals.

The results obtained are given in Table I., where the thermo-electric number of chemically pure silver is taken =0, and that of a certain commercial sort of copper =1.

TABLE I.

Bismuth (commercial, pressed wire)	+ 35·81
Bismuth (pure, pressed wire)	+ 32·91
Alloy of 32 parts of bismuth and 1 part of antimony (cast)	+ 29·06
Bismuth (pure, cast)	+ 24·96

* POGGENDORFF's Annalen, lxxxiii. p. 77; lxxxiv. p. 75; lxxxix. p. 90.

† GEHLER, Physikalisches Wörterbuch, B. 9. Ab. 1. S. 776.

Bismuth (crystal, axial)	+24·59
Bismuth (crystal, equatorial)	+17·17
Cobalt No. 1 (a pressed specimen prepared by Professor DUFLOS, and out of the Collection of the Heidelberg Chemical Laboratory)	+ 8·977
Potassium (the same as used for the determination of its electric conducting powers for different temperatures)	+ 5·492
Argentine (wire of commerce, hard drawn)	+ 5·240
Nickel (commercial, free from cobalt, but containing iron, &c.) (from Messrs. EVANS and ATKIN, Birmingham)	+ 5·020
Cobalt No. 2 (from the Collection of the Heidelberg Laboratory)	+ 3·748
Palladium (wire, hard drawn, from DESMOUTIS, CHAPUIS and Co. of Paris)	+ 3·560
Sodium (the same as used for the determination of its electric conducting powers for different temperatures)	+ 3·094
Quicksilver (pure, fused in a glass tube)	+ 2·524
Aluminium (from ROUSSEAU Frères of Paris, wire, hard drawn, analysed by Dr. G. C. CALDWELL, and found to contain Si 2·34, Fe 5·89, and Al 91·77)	+ 1·283
Magnesium (wire, pressed)	+ 1·175
Lead (pure, pressed wire)	+ 1·029
Tin (pure, pressed wire). The difference of the electromotive powers of the elements was here so small that it could not be determined; with the galvanometer, a copper-tin element, when the soldered points had 100° C. difference, gave no appreciable deflection; also the central experiments show as well how very little the electromotive power of a silver-tin thermo-element varies from a silver-copper one	+ 1·000
Copper No. 1 (wire of commerce, annealed, containing small quantities of zinc, tin, lead and nickel)	+ 1·000
Copper No. 2 (wire of commerce, annealed)	+ 0·922
Platinum (wire from DESMOUTIS, CHAPUIS and Co. of Paris)	+ 0·723
Gold (wire, hard drawn, purified by Dr. C. MEYBOOM)	+ 0·613
Iridium (from the Collection of the Heidelberg Chemical Laboratory)	+ 0·163
Antimony (wire, pressed specimens, purified by Dr. W. P. DEXTER and Dr. G. C. CALDWELL)	+ 0·036
Silver (pure, drawn, hard)	0·000
Gas-coke (from the Heidelberg Gas-Manufactory, the hard mass remaining in the retorts)	− 0·057
Zinc (pure, pressed)	− 0·208
Copper (galvanoplastically precipitated)	− 0·244
Cadmium (a pure slip of foil from Professor BÖTTGER)	− 0·332
Antimony (commercial, pressed wire)	− 1·897
Strontium (pressed wire)	− 2·028
Lithium (pressed wire)	− 3·768
Arsenic (a piece, pure)	− 3·828

Calcium (pressed wire)	— 4·260
Iron (pianoforte wire No. 4)	— 5·218
Antimony (axial)	— 6·965
Antimony (equatorial)	— 9·435
Red phosphorus (from Professor SCHRÖTTER, from the Collection of the Heidelberg Chemical Laboratory)	— 9·600
Antimony (purified as above, cast)	— 9·871
An alloy of 12 parts of bismuth, 1 part of tin, cast	— 13·670
An alloy of 2 parts of antimony and 1 part of zinc, cast	— 22·700
Tellurium (from M. ALEXANDER LOEWE of Vienna, purified by M. HOLTZMANN, cast)	—179·80
Selenium (from the Collection of the Heidelberg Chemical Laboratory	—290·00

The electromotive power of a copper No. 1, Argentine thermo-elements, whose soldering-points had the temperatures 7° and 25°, was found by Dr. WILD to be equal to $18{\cdot}4.10^6$ in the standard given by Professor WEBER, where the unit of length is 1 millimetre, the mass a milligram, and the time a second; and that of the same thermo-element, where the difference of temperature at the soldering-points was 100° C., was found equal to 1·108 compared with that of a DANIELL's element, the electromotive power of which was taken equal 1000*.

The above series agrees with that found by SEEBECK, with the exception of arsenic, which stands below iron according to his experiments; this however is easily explained, as different sorts of iron give with each other strong thermo-electric currents.

The manner in which the experiments were carried out is the following:—Two thermo-elements, whose warm and cold soldering-points had the same temperatures, were compared with each other; these formed a circuit with the coil of a galvanometer, which surrounded a magnet rod of about a pound weight, to which was fastened a piece of looking-glass, thereby allowing the deflections of the magnet to be observed at a distance by means of a telescope and scale, in the same way as observations are made with the magnetometer. The commutators were brought into the circuit; the one changed the direction of the current in the wire of the multiplier, and the other allowed the currents of the thermo-elements either to pass in a direction so that they strengthened, or so that they opposed each other.

Out of the four observed stationary deflections of the magnet which correspond with the four different possible positions of the commutators, the ratio of the electromotive powers of the two thermo-elements may easily be calculated; for if s_1, s_2, s_3, s_4 be the four observed deflections, and if s_1 and s_4 be the combination of the two warm soldering-points of the two elements, and s_2 and s_3 that of the warm soldering-points of the one with the cold one of the other, that ratio is $=\frac{(s_2-s_3)+(s_1-s_4)}{(s_2-s_3)-(s_1-s_4)}$.

All the solderings of the different metals were placed in two cubical zinc boxes (of about 6 inches the side); these had double sides, the space between them being filled

* POGGENDORFF's Annalen, vol. ciii. p. 353.

with ashes. The one box was filled with warm water, and the other with water having the temperature of the room; the wires were introduced partly through holes in the covers and partly through holes in the sides, which were made water-tight with india-rubber tubing. In order to prevent any conducting of the electric current through the water, the wires were covered with thin india-rubber tubes, and by means of stirrers a uniformity of temperature was kept up throughout each of the boxes. In consequence of their size and their double sides, the temperature hardly varied during the time an observation was being made. If the electromotive powers of a thermo-element were in exact ratio with the difference of the temperatures, the knowledge of the same would not be necessary with the arrangement described; but as this is not exactly the case, the temperatures were observed by means of thermometers placed in the boxes through the covers. Table II., the arrangement of which will be explained immediately, contains the results of the observations made in the manner above described.

TABLE II.

Silver, *Bismuth* (commercial wires)—5 Silver, Copper.

			Mean.
$t_1=7{\cdot}6$	$t_2=24{\cdot}0$	$v=7{\cdot}163$	7·162
$t_1=7{\cdot}6$	$t_2=23{\cdot}0$	$v=7{\cdot}164$	
$t_1=7{\cdot}6$	$t_2=22{\cdot}4$	$v=7{\cdot}159$	

Silver, *Bismuth* (pure wires)—5 Silver, Copper.

$t_1=4{\cdot}2$	$t_2=23{\cdot}7$	$v=6{\cdot}585$	6·582
$t_1=4{\cdot}2$	$t_2=22{\cdot}6$	$v=6{\cdot}586$	
$t_1=4{\cdot}2$	$t_2=21{\cdot}8$	$v=6{\cdot}575$	

Silver, *Potassium*—2 Silver, Copper.

$t_1=4{\cdot}0$	$t_2=29{\cdot}3$	$v=2{\cdot}748$	2·746
$t_1=4{\cdot}0$	$t_2=27{\cdot}3$	$v=2{\cdot}749$	
$t_1=4{\cdot}0$	$t_2=25{\cdot}9$	$v=2{\cdot}742$	

Silver, *Argentine*—2 Silver, Copper.

$t_1=5{\cdot}6$	$t_2=32{\cdot}1$	$v=2{\cdot}620$	2·620
$t_1=5{\cdot}6$	$t_2=31{\cdot}0$	$v=2{\cdot}621$	
$t_1=5{\cdot}6$	$t_2=30{\cdot}0$	$v=2{\cdot}620$	

Silver, *Palladium*—2 Silver, Copper.

$t_1=4{\cdot}4$	$t_2=27{\cdot}7$	$v=1{\cdot}783$	1·780
$t_1=4{\cdot}4$	$t_2=27{\cdot}2$	$v=1{\cdot}775$	
$t_1=4{\cdot}4$	$t_2=26{\cdot}0$	$v=1{\cdot}782$	

Silver, *Sodium*—2 Silver, Copper.

$t_1=4{\cdot}8$	$t_2=28{\cdot}9$	$v=1{\cdot}549$	1·547
$t_1=4{\cdot}8$	$t_2=27{\cdot}0$	$v=1{\cdot}546$	
$t_1=4{\cdot}8$	$t_2=26{\cdot}1$	$v=1{\cdot}550$	
$t_1=4{\cdot}8$	$t_2=26{\cdot}0$	$v=1{\cdot}544$	

TABLE II. (Continued.)

Silver, *Quicksilver*—2 Silver, Copper.

			Mean.
$t_1 =$ 7·2	$t_2 =$ 28·3	$v =$ 1·265	1·262
$t_1 =$ 7·2	$t_2 =$ 27·8	$v =$ 1·262	
$t_1 =$ 7·2	$t_2 =$ 27·0	$v =$ 1·259	

2 Silver, Copper—Silver, *Aluminium*.

$t_1 =$ 5·0	$t_2 =$ 28·0	$v =$ 1·559	1·558
$t_1 =$ 5·0	$t_2 =$ 26·9	$v =$ 1·558	
$t_1 =$ 5·0	$t_2 =$ 26·0	$v =$ 1·558	

2 Silver, Copper—Silver, *Magnesium*.

$t_1 =$ 6·8	$t_2 =$ 30·1	$v =$ 1·698	1·702
$t_1 =$ 6·8	$t_2 =$ 29·8	$v =$ 1·704	
$t_1 =$ 6·8	$t_2 =$ 27·5	$v =$ 1·703	

Silver, *Lead*—Silver, Copper.

$t_1 =$ 9·0	$t_2 =$ 29·2	$v =$ 1·031	1·029
$t_1 =$ 9·0	$t_2 =$ 28·8	$v =$ 1·031	
$t_1 =$ 9·0	$t_2 =$ 27·4	$v =$ 1·025	

Silver, Copper—Silver, *Copper* (No. 2).

$t_1 =$ 25·2	$t_2 =$ 42·9	$v =$ 1·084	1·084
$t_1 =$ 25·2	$t_2 =$ 42·2	$v =$ 1·083	
$t_1 =$ 25·2	$t_2 =$ 43·9	$v =$ 1·085	

Silver, Copper—Silver, *Platinum*.

$t_1 =$ 26·2	$t_2 =$ 44·0	$v =$ 1·385	1·383
$t_1 =$ 26·2	$t_2 =$ 43·8	$v =$ 1·388	
$t_1 =$ 26·2	$t_2 =$ 42·0	$v =$ 1·376	

2 Silver, *Gold*—Silver, Copper.

$t_1 =$ 4·5	$t_2 =$ 32·4	$v =$ 1·224	1·226
$t_1 =$ 4·5	$t_2 =$ 31·3	$v =$ 1·222	
$t_1 =$ 4·5	$t_2 =$ 30·0	$v =$ 1·230	
$t_1 =$ 4·5	$t_2 =$ 29·0	$v =$ 1·229	

2 Silver, Copper—2 *Zinc*, Silver.

$t_1 =$ 7·0	$t_2 =$ 30·4	$v =$ 4·822	4·810
$t_1 =$ 7·0	$t_2 =$ 29·1	$v =$ 4·800	
$t_1 =$ 7·0	$t_2 =$ 26·6	$v =$ 4·808	

Silver, Copper—*Cadmium*, Silver.

$t_1 =$ 5·4	$t_2 =$ 26·7	$v =$ 3·002	3·007
$t_1 =$ 5·4	$t_2 =$ 25·8	$v =$ 3·008	
$t_1 =$ 5·4	$t_2 =$ 25·2	$v =$ 3·011	

TABLE II. (Continued.)

2 Silver, Copper—*Antimony* (commercial wire) Silver.

			Mean.
$t_1 =$ 8·0	$t_2 =$ 33·0	$v =$ 1·059	1·054
$t_1 =$ 8·0	$t_2 =$ 31·2	$v =$ 1·055	
$t_1 =$ 8·0	$t_2 =$ 30·4	$v =$ 1·052	

Lithium, Silver—2 Silver, Copper.

$t_1 =$ 5·2	$t_2 =$ 32·5	$v =$ 1·888	1·884
$t_1 =$ 5·2	$t_2 =$ 31·5	$v =$ 1·887	
$t_1 =$ 5·2	$t_2 =$ 30·0	$v =$ 1·880	
$t_1 =$ 5·2	$t_2 =$ 29·0	$v =$ 1·881	

Calcium, Silver—2 Silver, Copper.

$t_1 =$ 4·3	$t_2 =$ 28·8	$v =$ 2·132	2·130
$t_1 =$ 4·3	$t_2 =$ 28·0	$v =$ 2·129	
$t_1 =$ 4·3	$t_2 =$ 26·9	$v =$ 2·129	

Iron, Silver—2 Silver, Copper.

$t =$ 6·0	$t_2 =$ 28·8	$v =$ 2·616	2·609
$t_1 =$ 6·0	$t_2 =$ 26·2	$v =$ 2·608	
$t_1 =$ 6·0	$t_2 =$ 29·8	$v =$ 2·604	

Antimony (pure wire), Argentine—Lead, Argentine.

$t_1 =$ 9·5	$t_2 =$ 35·1	$v =$ 1·234	1·236
$t_1 =$ 9·5	$t_2 =$ 33·9	$v =$ 1·236	
$t_1 =$ 9·5	$t_2 =$ 32·9	$v =$ 1·237	

Copper (galvanoplastic), Copper—Silver, Copper.

$t_1 =$ 26·2	$t_2 =$ 48·0	$v =$ 1·240	1·244
$t_1 =$ 26·2	$t_2 =$ 46·5	$v =$ 1·246	
$t_1 =$ 26·2	$t_2 =$ 45·7	$v =$ 1·247	

Strontium, Argentine—Silver, Argentine.

$t_1 =$ 6·0	$t_2 =$ 36·1	$v =$ 1·383	1·387
$t_1 =$ 6·0	$t_2 =$ 34·7	$v =$ 1·390	
$t_1 =$ 6·0	$t_2 =$ 33·1	$v =$ 1·389	

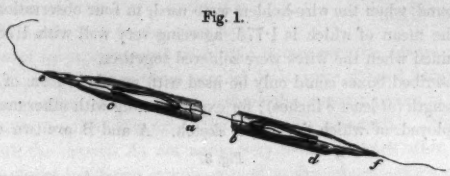
All the temperatures are given in Celsius's degrees. For the first experiment of the series, a thermo-element formed out of commercial bismuth (pressed wire), and silver was compared with a thermo-battery composed of five silver-copper elements. The silver and copper were the same sorts as those whose thermo-electric constants were taken $=0$ and 1. The temperature (t_1) of the water in the box containing the cold soldering-points was 7°·6, and that of the warm (t_2), 24°·0. The ratio of the electromotive force of the two elements (v) was found $=7·163$, in two other experiments, 7·164 and 7·157. The mean of these three numbers is 7·162, and therefore the electromotive force of a bismuth-silver element $=35·81$, that of a silver-copper one, or in other

words, the thermo-electric constant of commercial bismuth (pressed wire), $=35{\cdot}81$. All the other numbers in the Table have a similar meaning, and the metals, whose thermo-electric numbers are calculated out of them, are written in italics.

The connexion was, in all cases where the metal allowed of it, formed by soldering. Antimony wire, which (as well as that of tellurium) is so brittle that it will hardly bear touching, could of course not be directly soldered, but had to be treated in the following manner. The wire was pressed in a glass tube, in which it was soldered to two thick copper wires with ROSE's metal; these, in order to keep them from moving, were made fast in the tube with gypsum.

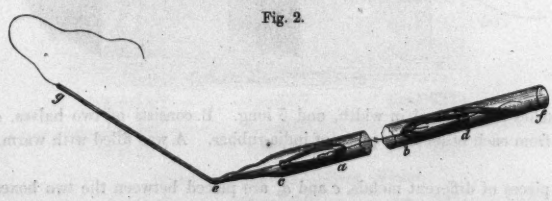
Lithium, calcium, strontium, and magnesium were experimented with in sealed-up glass tubes filled with rock oil, as fig. 1 shows, the ends of the wire being held at *a*

Fig. 1.



and *b* by two steel wire-holders, whose jaws press so strongly together that they flatten out the ends of the wire. At the other end of the wire-holders platinum wires were soldered on, which passed out of the tube at *c* and *d*. The way in which this piece of apparatus was put together is as follows:—a long platinum wire, soldered on to one of the wire-holders, was passed through a glass tube (drawn out and bent as shown in fig. 2) at *f*, so that the end of it came out at *g*, whilst the wire-holder remained outside

Fig. 2.

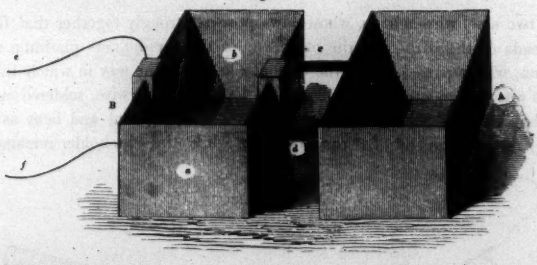


the other end at *f*. The glass tube being then laid in a trough filled with rock oil, the wire, previously pressed in a tube filled with the same liquid, was then taken out of the tube in the trough, the one end of it scraped clean and fastened in the wire-holder, and drawn into the tube by means of the long platinum wire, until only the other end of it remained out; this also having been scraped clean and fastened in the second wire-holder, was drawn into the tube as far as fig. 2 shows. The tube was now lifted out of the trough in an inclined position, so that it almost remained filled with the oil, and sealed up at *g*; at *f* it was then drawn out, the oil boiled to drive out the air, and sealed up

as shown in fig. 1; and lastly, the long end of the glass was melted off at *c*, and the superfluous platinum wire cut off. During the experiments the tube was so placed that the one end found itself in the middle of the one, and the other in the middle of the other box; that filled with warm water was placed higher than the other, in order that the tube might remain in an inclined position, preventing thereby the warming of the other end through currents which would otherwise have arisen in the oil. The connexion was now formed by soldering on the silver or other wires to the platinum ones. To ascertain whether this arrangement would give correct results, a silver-palladium element was compared with two composed of silver-copper; in the one case the palladium wire was fastened in the wire-holders as above described, in the other it was soldered directly to the silver. The ratio of the electromotive power of the two elements was found, when the wire-holders were used, in four observations, 1·779, 1·776, 1·767, 1·777, the mean of which is 1·775, agreeing very well with 1·780, the mean of the results obtained when the wires were soldered together.

The above-described boxes could only be used with metals in form of wire, or rods of a considerable length (at least 8 inches); for experimenting with other metals two smaller boxes were employed, of which fig. 3 is a sketch. A and B are two copper boxes of

Fig. 3.



about 4 inches in height, 4 in width, and 5 long. B consists of two halves, *a* and *b*, insulated from each other by a piece of india-rubber. A was filled with warm, B with cold oil.

If two pieces of different metals, *c* and *d*, are placed between the two boxes, which are pressed against each other by screws, and if the two wires *e* and *f*, soldered to the two halves of B, be connected, a current is formed in the circuit whose electromotive power is equal to that of a thermo-element constructed with the metals *c* and *d*, whose extremities have the temperature of the oil in the boxes. To determine this electromotive power, a circuit was formed with the wires of the multiplier used for the former experiments, the two wires *e* and *f*, and the wires of one or more thermo-elements made of wires whose soldering-points dipped alternately in the oil of each box. The two commutators were again brought into the circuit, and answered the same pur-

pose as before. Where two or more thermo-elements were used, as was generally the case, they were fixed in a piece of wood, as fig. 4 shows, and which needs no explanation. With the same apparatus the difference in the thermo-electric behaviour of the cleavage planes of bismuth and antimony crystals was studied. The bismuth crystals had about 8 millims. the sides; two cleavage planes were made perpendicular to the principal axis, and two parallel to it. As antimony crystals could not be obtained large enough for these experiments, pieces were cut out of commercial antimony, as FRANZ did for his research on the same subject*. These were so experimented with, that in one case the planes perpendicular to the principal axis, in the other those parallel to it, were pressed between the sides of the boxes. The position of the crystals, where the current passes in the direction of the principal axis, is called the axial, the other the equatorial. The results of the observations with the crystals do not agree very well with each other, owing probably to the cleavage planes not being exactly ground at the proper angles, and also to their being placed in a rather oblique position between the boxes. Table III. gives the results obtained with the copper boxes.

Fig. 4.

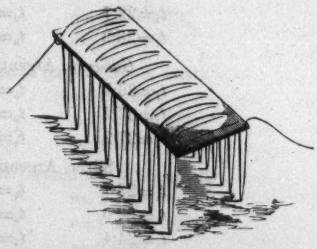


TABLE III.

7 Copper, Argentine—Argentine, *Bismuth* (pure cast).

			Mean.
$t_1=25^\circ\cdot5$	$t_2=47^\circ\cdot0$	$v=1\cdot503$	
$t_1=25\cdot8$	$t_2=40\cdot4$	$v=1\cdot509$	1·505
$t_1=25\cdot5$	$t_2=38\cdot7$	$v=1\cdot504$	

Silver, *Cobalt* (No. 1)—Silver, Argentine.

$t_1=18\cdot7$	$t_2=43\cdot7$	$v=1\cdot722$	
$t_1=18\cdot7$	$t_2=40\cdot0$	$v=1\cdot710$	1·713
$t_1=19\cdot3$	$t_2=36\cdot8$	$v=1\cdot708$	

Silver, Argentine—Silver, *Nickel*.

$t_1=20\cdot5$	$t_2=56\cdot0$	$v=1\cdot040$	
$t_1=20\cdot6$	$t_2=50\cdot2$	$v=1\cdot048$	1·044
$t_1=21\cdot0$	$t_2=44\cdot6$	$v=1\cdot044$	

Silver, Argentine—Silver, *Cobalt* (No. 2).

$t_1=21\cdot2$	$t_2=60\cdot0$	$v=1\cdot389$	
$t_1=21\cdot4$	$t_2=53\cdot0$	$v=1\cdot409$	1·398
$t_1=21\cdot7$	$t_2=47\cdot7$	$v=1\cdot395$	

* POGGENDORFF's Annalen, vol. lxxxiii. p. 374.

Silver, Argentine—*Iridium*, Argentine.

			Mean.
$t_1=22\cdot5$	$t_2=49\cdot8$	$v=1\cdot029$	1·032
$t_1=22\cdot7$	$t_2=46\cdot8$	$v=1\cdot039$	
$t_1=23\cdot2$	$t_2=45\cdot3$	$v=1\cdot027$	

Gas-coke, Argentine—Silver, Argentine.

$t_1=26\cdot7$	$t_2=57\cdot5$	$v=1\cdot010$	1·011
$t_1=27\cdot2$	$t_2=56\cdot4$	$v=1\cdot012$	
$t_1=27\cdot2$	$t_2=51\cdot9$	$v=1\cdot012$	

Silver, Argentine—*Arsenic*, Silver.

$t_1=23\cdot7$	$t_2=43\cdot3$	$v=1\cdot368$	1·369
$t_1=24\cdot0$	$t_2=40\cdot5$	$v=1\cdot372$	
$t_1=24\cdot4$	$t_2=36\cdot9$	$v=1\cdot366$	

Antimony (pure cast), Silver—Silver, Argentine.

$t_1=22\cdot3$	$t_2=57\cdot8$	$v=1\cdot884$	1·884
$t_1=22\cdot5$	$t_2=53\cdot5$	$v=1\cdot882$	
$t_1=23\cdot1$	$t_2=48\cdot2$	$v=1\cdot886$	

Tellurium, Silver—19 Copper, Argentine.

$t_1=17\cdot0$	$t_2=36\cdot2$	$v=2\cdot259$	2·232
$t_1=17\cdot5$	$t_2=32\cdot6$	$v=2\cdot235$	
$t_1=18\cdot3$	$t_2=29\cdot7$	$v=2\cdot215$	
$t_1=18\cdot5$	$t_2=37\cdot5$	$v=2\cdot214$	
$t_1=18\cdot8$	$t_2=32\cdot1$	$v=2\cdot235$	
$t_1=19\cdot1$	$t_2=30\cdot6$	$v=2\cdot228$	

Silver, *Bismuth-Antimony*—Silver, Argentine.

$t_1=24\cdot6$	$t_2=58\cdot2$	$v=5\cdot525$	5·546
$t_1=24\cdot8$	$t_2=56\cdot4$	$v=5\cdot575$	
$t_1=25\cdot2$	$t_2=54\cdot1$	$v=5\cdot538$	

Bismuth-Tin, Silver—Silver, Argentine.

$t_1=26\cdot2$	$t_2=56\cdot5$	$v=2\cdot609$	2·608
$t_1=26\cdot6$	$t_2=53\cdot6$	$v=2\cdot617$	
$t_1=27\cdot0$	$t_2=51\cdot0$	$v=2\cdot598$	

Antimony-Zinc, Silver—Silver, Argentine.

$t_1=24\cdot3$	$t_2=51\cdot5$	$v=4\cdot329$	4·333
$t_1=24\cdot6$	$t_2=49\cdot3$	$v=4\cdot325$	
$t_1=25\cdot0$	$t_2=47\cdot5$	$v=4\cdot345$	

5 Silver, Argentine—Silver, *Bismuth* (crystal axial).

$t_1=30\cdot0$	$t_2=45\cdot6$	$v=1\cdot152$	1·154
$t_1=30\cdot5$	$t_2=44\cdot6$	$v=1\cdot150$	
$t_1=31\cdot2$	$t_2=42\cdot8$	$v=1\cdot160$	

5 Silver, Argentine—Silver, *Bismuth* (crystal No. 1, equatorial).

			Mean.
$t_1=31°\cdot2$	$t_2=58°\cdot1$	$v=1\cdot706$	1·702
$t_1=32\cdot5$	$t_2=48\cdot7$	$v=1\cdot700$	
$t_1=32\cdot5$	$t_2=48\cdot1$	$v=1\cdot700$	

5 Silver, Argentine—Silver, *Bismuth* (crystal No. 2, axial).

$t_1=30\cdot0$	$t_2=44\cdot3$	$v=1\cdot073$	1·075
$t_1=30\cdot0$	$t_2=42\cdot7$	$v=1\cdot070$	
$t_1=30\cdot2$	$t_2=41\cdot2$	$v=1\cdot081$	

5 Silver, Argentine—Silver, *Bismuth* (crystal No. 2, equatorial).

$t_1=28\cdot7$	$t_2=39\cdot5$	$v=1\cdot492$	1·499
$t_1=28\cdot7$	$t_2=39\cdot5$	$v=1\cdot494$	
$t_1=29\cdot0$	$t_2=51\cdot0$	$v=1\cdot500$	

Silver, *Bismuth* (crystal No. 3, axial)—5 Silver, Argentine.

$t_1=26\cdot2$	$t_2=45\cdot1$	$v=1\cdot014$	1·012
$t_1=26\cdot3$	$t_2=43\cdot4$	$v=1\cdot012$	
$t_1=27\cdot5$	$t_2=40\cdot8$	$v=1\cdot012$	

5 Silver, Argentine—Silver, *Bismuth* (crystal No. 3, equatorial).

$t_1=28\cdot7$	$t_2=40\cdot0$	$v=1\cdot446$	1·442
$t_1=28\cdot7$	$t_2=39\cdot3$	$v=1\cdot441$	
$t_1=28\cdot7$	$t_2=38\cdot7$	$v=1\cdot438$	

5 Silver, Argentine—Silver, *Bismuth* (crystal No. 4, axial).

$t_1=27\cdot0$	$t_2=50\cdot2$	$v=1\cdot660$	1·661
$t_1=27\cdot4$	$t_2=46\cdot6$	$v=1\cdot662$	

5 Silver, Argentine—Silver, *Bismuth* (crystal No. 4, equatorial).

$t_1=27\cdot6$	$t_2=50\cdot2$	$v=1\cdot243$	1·240
$t_1=27\cdot8$	$t_2=46\cdot6$	$v=1\cdot237$	

2 Silver, Argentine—*Antimony*, No. 1 (axial), Silver.

$t_1=23\cdot8$	$t_2=34\cdot5$	$v=1\cdot485$	1·493
$t_1=23\cdot8$	$t_2=38\cdot0$	$v=1\cdot500$	
$t_1=24\cdot0$	$t_2=35\cdot5$	$v=1\cdot495$	

2 Silver, Argentine—*Antimony*, No. 1 (equatorial), Silver.

$t_1=22\cdot4$	$t_2=39\cdot0$	$v=1\cdot079$	1·090
$t_1=22\cdot4$	$t_2=36\cdot5$	$v=1\cdot090$	
$t_1=22\cdot8$	$t_2=35\cdot7$	$v=1\cdot103$	

2 Silver, Argentine—*Antimony*, No. 2 (axial), Silver.

$t_1=22\cdot6$	$t_2=46\cdot2$	$v=1\cdot521$	1·517
$t_1=22\cdot8$	$t_2=43\cdot4$	$v=1\cdot517$	
$t_1=23\cdot0$	$t_2=44\cdot8$	$v=1\cdot514$	

2 Silver, Argentine—*Antimony*, No. 2 (equatorial), Silver.

			Mean.
$t_1=23^\circ\cdot0$	$t_2=42^\circ\cdot0$	$v=1\cdot314$	1·317
$t_1=23\cdot0$	$t_2=40\cdot5$	$v=1\cdot315$	
$t_1=23\cdot2$	$t_2=32\cdot2$	$v=1\cdot321$	

As tellurium takes such an extraordinary place in the series, it seemed interesting to make a few experiments with a thermo-battery constructed out of tellurium-bismuth; and one composed of eight of these elements, whose soldering-points had but 60° temperature difference, decomposed a solution of sulphate of copper. A thermo-battery, made of 100 pairs of tellurium-bismuth, whose extremities have 100° temperature difference, will give an electromotive power equal to four of DANIELL's cells. Such a thermo-battery I am at present constructing.

Selenium and red phosphorus conduct electricity, but so badly, that the galvanometer used in all the former experiments could not here be used, and in its stead an astatic multiplier, with 20,000 folds of wires, was employed. As the deflections of the needle were very small, in the calculation the angle of deflection may be said to be proportional to the electromotive forces. Table IV. contains the results obtained with the astatic multiplier and the copper boxes.

TABLE IV.

2 Silver, Argentine—*Red Phosphorus* (only filed, not coppered), Silver.

$v=1\cdot08$

2 Silver, Argentine—*Red Phosphorus* (coppered), Silver.

$v=1\cdot07$

Selen, Bismuth—19 Copper, Argentine.

$v=3\cdot57$, $v=3\cdot62$ } 36·0

From the values of the thermo-electric numbers of the different metals given in Table I., the ratio of the electromotive power of two elements constructed out of any two of those metals may be calculated. In order, therefore, to ascertain the accuracy of these values, several combinations were made, and their electromotive powers determined. In the following Tables the ratio of the electromotive powers for the different combinations is given.

TABLE V. Experiments made with the large zinc boxes and the multiplier.

	Ratio. Found.	Ratio. Calculated.
Silver, Bismuth (commercial wire)—Silver, Bismuth, Silver, Bismuth (pure wire)	1·097	1·088
Silver, Potassium—Silver, Palladium	1·543	1·542
Silver, Argentine—Silver, Palladium	1·467	1·472

TABLE V. (Continued.)

	Ratio. Found.	Ratio. Calculated.
Silver, Palladium—Silver, Sodium	1·153	1·151
Copper, Potassium—Copper, Sodium	2·149	2·145
Silver, Quicksilver—Silver, Aluminium	1·967	1·967
Silver, Quicksilver—Silver, Magnesium	2·129	2·143
Silver, Lead—Silver, Tin	1·027	1·029
Silver, Copper (No. 2)—Silver, Platinum	1·280	1·275
2 Silver, Gold—Silver, Tin	1·223	1·226
2 Zinc, Silver—Cadmium, Silver	1·245	1·253
Copper (precipitated galvanoplastically), Argentine—Aluminium, Argentine	1·370	1·385
Antimony (pure wire), Argentine—Copper, Argentine	1·228	1·227
Silver, Palladium—Antimony (commercial wire), Silver	1·900	1·876
Strontium, Argentine—Aluminium, Argentine	1·838	1·834
Lithium, Silver—Silver, Palladium	1·056	1·058
Iron, Silver—Calcium, Silver	1·220	1·224

TABLE VI. Experiments with the copper boxes and multiplicator.

Silver, Argentine—Bismuth, alloy of Bismuth, Antimony	1·330	1·278
7 Copper, Argentine—Silver, Bismuth (pure cast)	1·198	1·189
Silver, Argentine—Argentine, Cobalt (No. 1)	1·422	1·403
Silver, Argentine—Cobalt (No. 2), Argentine	3·497	3·510
Silver, Argentine—Copper, Nickel	1·293	1·303
Silver, Argentine—Iridium, Palladium	1·570	1·542
Silver, Argentine—Gas-coke, Palladium	1·479	1·448
Silver, Argentine—Arsenic, Copper	1·104	1·086
Antimony (pure cast), Copper—Silver, Argentine	2·068	2·074
Alloy of Bismuth, Tin, alloy of Antimony, Zinc—Silver, Argentine	1·729	1·723

TABLE VII. Experiments with the copper boxes and the astatic multiplier.

Red Phosphorus (coppered), Copper—2 Silver, Argentine	1·040	1·010
Red Phosphorus (coppered), Argentine—2 Silver, Argentine	1·390	1·410
Selen, Antimony—19 Copper, Argentine	4·370	4·370
Selen, Tellurium—19 Copper, Argentine	2·510	2·610

In conclusion, I may here be allowed to express my thanks to Professor KIRCHHOFF for his valuable advice and assistance whilst carrying out this research, and also to Professor BUNSEN for his kindness in having placed his collection of metals at my disposal.

XX. *On the Electric Conducting Power of the Metals.* By AUGUSTUS MATTHIESSEN, *Ph.D.* *Communicated by* CHARLES WHEATSTONE, *Esq.*, *F.R.S.*

Received November 20, 1857,—Read January 14, 1858.

REQUIRING for my research on thermo-electricity a great many metals, which were for the most part chemically pure, I thought it would be interesting to determine at the same time their electric conducting power. The method used for these determinations was the same as that described in the Philosophical Magazine (February 1857), and the experiments were made in the Heidelberg Physical Laboratory under the direction of Professor KIRCHHOFF.

The values given in the following series are the results obtained with different wires of the same metal compared with silver, 100 at 0°.

	Conducting power.	Temperature. °C.	Mean of conducting power.	Temperature. °C.
Silver	100	at 0	100	0
Copper, No. 3	77·43	at 18·8	77·43	18·8
Copper, No. 2	72·70 71·43	at 22·6 at 22·6	72·06	22·6
Gold	55·16 55·24 55·17	at 21·6 at 21·8 at 22·0	55·19	21·8
Sodium			37·43	21·7
Aluminium	33·44 33·75 34·09	at 19·2 at 19·4 at 20·0	33·76	19·6
Copper, No. 1	30·36 30·70 30·55 30·90	at 24·0 at 24·0 at 24·2 at 24·5	30·63	24·2
Zinc	27·41 27·42 27·34	at 17·4 at 17·6 at 17·8	27·39	17·6
Magnesium			25·47	17·0
Calcium			22·14	16·8
Cadmium	22·05 22·09 22·16	at 18·8 at 18·8 at 18·8	22·10	18·8

FRANKLIN INSTITUTE LIBRARY.

	Conducting power.	Temperature. °C.	Mean of conducting power.	Temperature. °C.
Potassium			20·85	20·4
Lithium			19·00	20·0
Iron	14·64	at 21·2	14·44	20·4
	14·46	at 21·2		
	14·68	at 19·0		
	14·33	at 19·0		
	14·10	at 21·4		
Palladium	12·60	at 17·0	12·64	17·2
	12·63	at 17·2		
	12·69	at 17·4		
Tin	11·39	at 21·0	11·45	21·0
	11·40	at 21·0		
	11·56	at 21·0		
Platinum	10·55	at 20·4	10·53	20·7
	10·46	at 20·8		
	10·57	at 21·0		
Lead	7·84	at 17·2	7·77	17·3
	7·73	at 17·2		
	7·74	at 17·4		
Argentine	7·73	at 20·0	7·67	18·7
	7·62	at 17·4		
	7·67	at 18·8		
Strontium			6·71	20·0
Antimony	4·28	at 18·7	4·29	18·7
	4·30	at 18·7		
	4·29	at 18·7		
Quicksilver	1·64	at 22·8	1·63	22·8
	1·63	at 22·8		
	1·62	at 22·8		
Bismuth	1·18	at 14·5	1·19	13·8
	1·19	at 14·8		
	1·21	at 12·0		
	1·19	at 14·0		
Alloy of Bismuth 32 parts Antimony 1 part	0·880	at 24·0	0·884	24·0
	0·883	at 24·0		
	0·889	at 24·0		
Alloy of Bismuth 12 parts Tin 1 part	0·516	at 22·0	0·519	22·0
	0·536	at 22·0		
	0·505	at 22·0		

	Conducting power.	Temperature.	Mean of conducting power.	Temperature.
		° C.		° C.
Alloy of Antimony 2 parts	0·412	at 25·0	0·413	25·0
Zinc 1 part	0·414	at 25·0		
Graphite, No. 1	0·0719	at 22·0	0·0693	22·0
	0·0667	at 22·0		
Graphite, No. 2	0·0436	at 22·0	0·0436	22·0
	0·0436	at 22·0		
Gas-coke	0·0372	at 25·0	0·0386	25·0
	0·0405	at 25·0		
	0·0383	at 25·0		
Graphite, No. 3	0·00370	at 22·0	0·00395	22·0
	0·00420	at 22·0		
BUNSEN's battery-coke	0·00217	at 26·2	0·00246	26·2
	0·00289	at 26·2		
	0·00233	at 26·2		
Tellurium	0·000742	at 20·0	0·000777	19·6
	0·000795	at 20·0		
	0·000794	at 18·7		
Red phosphorus	0·00000118	at 20·0	0·00000123	20·0
	0·00000128	at 20·0		

For the determination of the conducting powers of these bodies, whose electric resistance was very great, a number of normal wires of different lengths were made, and by these means accurate results were obtained.

The conducting powers of potassium and sodium* are here given to make the series complete. The alloys of bismuth-tin, bismuth-antimony, and antimony-zinc were determined in order to ascertain whether, as they give with other metals such strong thermo-electric currents, they might be more advantageously employed for thermo-electric batteries than those constructed of bismuth and antimony.

All the metals were the same as those used for my thermo-electric experiments, with the exception of cadmium, which was purified by my friend Mr. B. JEGEL. Coppers Nos. 1, 2 and 3, were wires of commerce. In No. 1 small quantities of lead, tin, zinc, and nickel were found by Mr. HERSCHEL, who was kind enough to analyse it. The small conducting powers of this sort may be attributed, according to the opinion of Professor BUNSEN, to a trace of suboxide of copper probably contained in the same.

The values obtained for aluminium are nearly the same as those found by POGGENDORFF† and BUFF‡.

Iron, Nos. 1, 2 and 3, were pianoforte wires. These determinations, although higher

* Phil. Mag. Feb. 1857. † POGG. Ann. vol. xcix. p. 643. ‡ Ann. Chim. Pharm. vol. cii. p 265.

than those found by nearly all of the earlier experimenters, are in accordance with the results lately made known by BUFF.

The wires of bismuth employed for these experiments were of a very small diameter (0·144 millim. and 0·185 millim.); for when manipulating with thicker ones, very varying results were obtained, probably owing to the disposition of the crystals, as MATTEUCCI* has already observed. In fact, twelve experiments made with such wires, when the conducting power varied from 1·11 to 1·36, gave as a mean 1·20, which agrees pretty accurately with the number in the above series.

Graphite No. 1 is the so-called pure Ceylon, No. 3 the purified German, and No. 2 a mixture of both, all used for making pencils. The specimens were purified by BRODIE'S patent, and pressed by Mr. CARTMELL, to whom I am indebted for the same. These, as well as the gas-coke and BUNSEN'S battery-coke, were shaped into thin rods by hand, and the ends coppered galvanoplastically.

To form the connexion in order to determine their conducting powers, one end stood in a cup of quicksilver, the other cup being formed by placing an india-rubber tubing over the other end, the latter cup being of course also filled with quicksilver. As the rods were made by hand, the difference in the results of the same specimens is thus accounted for.

An interesting fact was now observed, viz. that in all the cokes and graphites the conducting power increased by heat. Some experiments were made with gas-coke, and it was found that if at 0° the conducting power equalled 100, it, from 0° to 140°, increased 0·00245 for each degree, and between the common temperature and a light red heat, about 12 per cent.

For these experiments the connecting copper wires were soldered on to the coppered ends of the rods. The red phosphorus was likewise coppered galvanoplastically, and the values determined after the same method.

The following metals were chemically pure:—Silver, gold, zinc, cadmium, tin, lead, antimony, quicksilver, bismuth, tellurium; and the undermentioned pressed, viz. sodium, zinc, magnesium, calcium, cadmium, potassium, tin, lead, strontium, antimony, bismuth, alloy of bismuth-antimony, alloy of bismuth-tin, and tellurium.

No difficulty was found in pressing the above-mentioned wires, only with antimony and tellurium care must be taken in heating the press of the former to a dark red heat, and of the latter until it burns blue.

Quicksilver was determined in glass tubes, and the alloy of antimony-zinc cast likewise in small glass tubes, it being too hard to press and too brittle to draw. The remainder of the wires were drawn.

In conclusion, I will record a few experiments on the alloys of lead, tin, zinc and cadmium. The alloys made of two of these metals appear to conduct electricity after a very simple law; namely, their conducting power is the mean of the conducting power of the quantity of each metal employed, as the following results show.

* Comptes Rendus, vol. xl. p. 541.

	Mean of conducting power.	Mean of temperature.	Calculated conducting power.
		°C.	
Sn Pb* . . .	9·20	21·4	9·09
Sn_4 Pb . . .	10·55	22·0	10·31
Sn Pb_4 . . .	8·26	22·6	8·22
Zn Sn† . . .	17·43	22·0	17·13
Zn Cd‡ . . .	23·78	20·8	24·04

The above values are the means of at least two agreeing results determined after the before-mentioned method, the metals being of course chemically pure.

With bismuth and antimony the same law does not appear to hold good; and how far with other metals this may be the case, I intend, as soon as I have procured a fresh supply of pure metals, to investigate and make known.

* If the equivalent of Sn = 58·0 and Pb = 103·7.

† If the equivalent of Zn = 32·6.

‡ This alloy was prepared by Mr. B. JEGEL, who took the equivalent of Zn = 32·53, and Cd = 55·74.

XXI. *On the Resistance of Tubes to collapse.*

By William Fairbairn, *Esq.*, *C.E.*, *F.R.S.*, *&c.*

Received April 21,—Read May 20, 1858.

The following experiments were undertaken at the joint request of the Royal Society and the British Association for the Advancement of Science. Their object is to determine the laws which govern the strength of cylindrical vessels exposed to a uniform external force, and their immediate practical application in proportioning more accurately the flues of boilers for raising steam, which have hitherto been constructed on merely empirical data.

It is well known that the immense extension of the application of steam power, and the consequent inducement to economise as far as possible the fuel necessary for its production, together with the growing tendency to employ the expansive principle, has caused a general increase of the working pressure from 10 lbs. to 50 lbs., and even in some cases to 150 lbs. on the square inch. Unfortunately, however, our knowledge of the principles of construction has not kept pace with our desire to economise, and hence the change has been accompanied by an increase of dangerous and fatal accidents from boiler explosions. Investigation has frequently shown these lamentable catastrophes to have arisen from ignorance of the immense elastic power of steam, and from a want of knowledge of the forms of construction best calculated to retain an agent of such potent force; and as explosions become more frequent in proportion as the pressure is increased, it is the more necessary to inquire into the causes of such disasters, and to apply such remedies as may effectually prevent them.

In order to save space and to increase the generative powers of boilers, *internal flues* and tubes have been generally adopted, and that without sufficient attention to proportioning their diameter, length, and thickness of plates, so as to ensure safety on the one hand, and economy of material in its judicious distribution on the other. Hitherto it has been considered an undisputed axiom among practical engineers, that a cylindrical tube, such as a boiler-flue, when subjected to a uniform external pressure, was equally strong in every part, and that the length did not affect the strength of a tube so placed. But although this rule may be true when applied to tubes of indefinite length, or to tubes unsupported by rigid rings at the extremities, it is very far from true where the lengths are restricted within certain apparently constant limits, and where the ends are securely fastened in frames, which prevent their yielding to an external force.

In some experimental tests to prove the efficiency of some large boilers, the author had some misgivings as to the strength of the internal flues to resist a force tending to

collapse them. In these experiments it was found that flues 35 feet long were distorted with considerably less force than others of a similar construction 25 feet long. This anomalous result led to further inquiry, which being far from satisfactory, the present series of experiments were instituted, with, it is believed, very conclusive results.

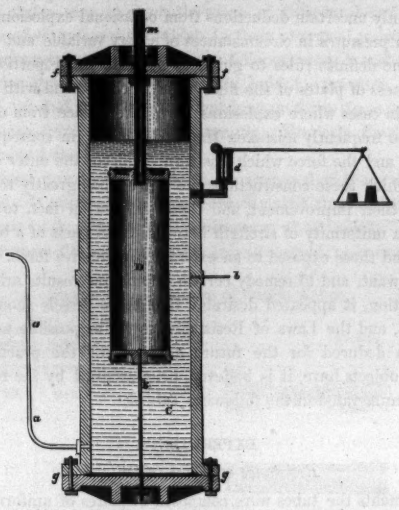
In order to have every facility for conducting these experiments, application was made to the Directors of the North-Eastern Division of the London and North-Western Railway, for permission to conduct them under their large octagonal engine-house at Longsight, near Manchester, where the necessary pumps and cranes were at hand. To this request the Directors gave their cordial assent, and in this position I had the benefit of the suggestions and experience of Mr. J. Ramsbottom, the Company's engineer, and also the constant attendance of Mr. R. B. Longridge, the engineer and chief inspector to the Association for the Prevention of Boiler Explosions. To both those gentlemen I tender my best acknowledgements for the able and efficient assistance I have received from them during the whole time occupied in conducting the experiments.

To attain the objects of the experiments in a satisfactory manner, it was necessary that the apparatus should be of great strength and of dimensions capable of receiving tubes of considerable length and diameter. For this purpose a cast-iron cylinder was prepared, 8 feet in length, 28 inches in diameter, and 2 inches thick of metal, for the reception of the tubes to be experimented upon. This cylinder, C, Plate XXVIII., was placed upon some balks of timber, in one of the locomotive pits, immediately under the shear-legs A, A, for the convenience of lifting and replacing the heavy cover of the cylinder, which had to be removed at the close of each experiment. A small pipe, *a*, *a*, connected the force-pump, B, with the interior of the cylinder; and another, *b*, *b*, communicated with the steam-pressure gauges at *c*, which exhibited the pressure in the cylinder during the experiment in lbs. per square inch: to ensure accuracy two gauges were employed, one of Schaeffer's and the other of Smith's construction, and the indications of these were checked by an accurate safety-valve, *d*. A small cock, *e*, served to let off the air contained in the cylinder when necessary.

Fig. 1 is a section of the large cylinder. The top and bottom covers, *f* and *g*, were made of strength proportionate to that of the cylinder, to which they were secured by 1-inch bolts placed 3 inches apart. In the bottom cover, *g*, a hole was drilled, to receive the rod and screw-nut *k*, which supported the tube D to be experimented upon; and through the top passed a 2½-inch pipe, *m*, inserted in the cast-iron end of the tube D. On the end of this pipe was a large nut, which screwed down upon an indian-rubber washer on the cover of the cylinder, so as to close the opening round the pipe and make it water-tight. The object of this pipe was to allow the air from the interior of the tube D to escape during the collapse, and so to place it, as nearly as possible, under the same circumstances as the flue of a boiler.

The whole of the experiments were effected by means of the hydraulic pump, by which water was forced through the pipe *a a* into the cylinder C; thus driving the air in a highly compressed state to the upper part of the cylinder, whence, when a very high

Fig. 1.—*Vertical section.*



pressure was required, it was deemed advisable to let it escape by the cock *e*, and to effect rupture through the medium of water only. In both these cases a perfectly uniform pressure was ensured upon every part of the tube to be collapsed.

These preparations having been made, and the pressure-gauges carefully adjusted, the experiments proceeded as shown in the following Tables.

The first experiment was upon a tube 4 inches in diameter, and 1 foot 7 inches long between the cast-iron ends, to which it was riveted securely and brazed. It was composed, as in the other experiments, of a single thin plate, bent to the required form upon a mandril, and riveted and also brazed to prevent leakage into the interior. This tube having been fixed to the cylinder covers in the manner described above, the pump was applied and a gradually-increasing force given to its exterior surface, until its powers of resistance were overcome. During the experiments the precaution of allowing the air to escape at high pressures was found absolutely necessary, as the tubes generally collapsed with an explosion of the suddenly-compressed air in the tube D, fig. 1, accompanied by a loud report as it made its escape by the pipe *m*. These explosions give pretty correct indications of what takes place when the internal flues of boilers collapse.

It has long been a desideratum to determine some law by which the engineer could calculate the proportionate strength of the internal flues. Hitherto we have acted upon the principle that the cylindrical flues, as ordinarily constructed, were considerably

stronger than the outer shell; but this opinion has in reality no foundation in experiment, excepting only uncertain deductions from occasional explosions and the failure of vessels under high pressures in circumstances of a very variable and doubtful character. There have been no definite rules to guide us hitherto in proportioning the diameter, length, and thickness of plates of the flues, so as to correspond with the strength of the boiler; and even in cases where explosions have taken place from collapse, we have, it is to be feared, too frequently mistaken the actual cause, in consequence of the débris covering the site, and the force which has torn to pieces the outer shell. The anomalous position in which these constructions are placed has greatly retarded the application of science to their improvement, and there appears, in fact, to be no rule known by which to attain uniformity of strength between those parts of a boiler exposed to an internal tensile, and those exposed to an external compressive force.

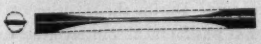
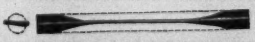
To supply this want, and to remedy certain anomalous results arising from defective forms of construction, it appeared desirable that these vessels should be subjected to direct experiment, and the Laws of Resistance as far as possible ascertained, and the necessary formula deduced for the future guidance of the practical mechanic and engineer. These objects have, it is believed, been attained by the results developed in the experiments enumerated in the following Tables.

EXPERIMENTS.

Resistance of Tubes to Collapse.

In these experiments the tubes were composed of plates of uniform thickness, and of the form and size shown by the figures in the column of remarks. The form after collapse is also indicated by the woodcuts.

TABLE I. Resistance of 4-inch Tubes.

Mark.	No.	Diameter. inches.	Length. inches.	Thickness of plates. inch.	Pressure of collapse. lbs. per sq. in.	Remarks.
A.	1	4	19	·043	170	N.B. The figures are drawn to a scale of ½ in. = 1 ft. The cross-sections are taken through the line *a b*, where the collapse was greatest. The dotted lines show their form before they were subjected to experiment.
B.	2	4	19	·043	137	
C.	3	4	40	·043	65	
D.	4	4	38	·043	65	
E.	5	4	60	·043	43	
F.	6	4	60	·043	140	

On consulting the above Table, it appears that tubes of the same diameter and the same thickness of plates vary in strength when of different lengths. The tubes of 19 inches and those of 40 inches differ widely in their powers of resistance. Comparing the results of Experiments 1 and 2 with those of Experiments 3 and 4, we find that the latter, while of twice the length, bear less than half the pressure. Comparing these with Experiment 5, we find that tube E, 5 feet long or three times as long as A and B, exhibits only about one-third of their mean strength. Similarly, E, which is $\frac{5}{3}$ the length of D, bears only about $\frac{3}{5}$ the pressure.

Tube F, Experiment 6, may be considered as composed of three distinct tubes, each 1 foot 7 inches long. It was made with two perfectly rigid rings, soldered to the outside of the tube to keep it in form and prevent collapse at those points. The result of this alteration was to increase the strength of the tube threefold, as is evident on comparing it with tube E.

TABLE II. Resistance of 6-inch Tubes.

Mark.	No.	Diameter. inches.	Length. inches.	Thickness. inches.	Pressure of collapse. lbs. per sq. in.	Remarks.
G.	7	6	30	·043	48*	
H.	8	6	29	·043	47*	
J.	9	6	59	·043	32	
K.	10	6	30	·043	52	
L.	11	6	30	·043	65	
M.	12	6	30	·043	85†	

This Table gives indications of the same law of resistance as the last. It will be

* On removing the tubes G, H, it was found, that owing to the thinness of the metal, the cast-iron ends of both had been fractured, causing collapse, perhaps, before the outer shell had attained its maximum resistance.

† Tube M had an iron rod down its axis to prevent the ends approaching each other during collapse; a tin ring had also been left in by mistake, which accounts for the increased pressure required to produce collapse.

observed that the tubes being screwed to the covers of the cylinder, were to some extent in a state of tension, owing to the necessity of having to screw up the air-tube tight in order to prevent leakage. This, with the weakness of the ends of the first two tubes, will account for the discrepancies in the Table. Making allowances on this ground and taking the mean of the experiments, we arrive at the conclusion that the results approximate closely to the law that the strengths are inversely as the length; and this, it will be observed, is the result arrived at in the comparison of the 4-inch tubes.

Thus the mean strength of the tubes, 30 inches long, experiments G, H, K, L, is 53 lbs per square inch. Now by the above inverse proportion, we may calculate from this the strength of a tube 59 inches long; thus,

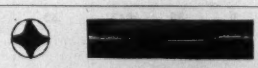
$$59 : 30 :: 52 : x = 27,$$

the result being 32 in the above Table, Experiment 9, a difference of 5 lbs. only.

This law receives remarkable confirmation from Experiment 6 on tube F. This tube had, as already explained, two rigid cast-iron rings firmly soldered to it so as to divide its length into three equal parts. The result was to increase the strength threefold, or, in other words, to make it equal in strength to a tube of one-third the length.

The next series of tubes submitted to experiment were 8 inches in diameter, and of the same thickness as the preceding. In these experiments it will be seen that the same law in respect of the length prevails, and is perhaps more strikingly exemplified than in either of the preceding series. Perhaps from their larger size these tubes were less affected by defects of workmanship. Like the last, they had an outlet for the escape of the air, and collapsed with loud reports.

TABLE III. Resistance of 8-inch tubes.

Mark.	No.	Diameter. inches.	Length. inches.	Thickness. inches.	Pressure of collapse. lbs. per sq. in.	Remarks.
N.	13	8	30	·043	39	
O.	14	8	39	·043	32	
P.	15	8	40	·043	31	

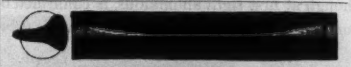
On comparing the above results, it will be found that there is a near approximation to the strengths being inversely as the lengths. Taking the strength of the first tube, 30 inches long, and calculating the force necessary to collapse the 39 and 40-inch tubes, we have, by calculation,

$$39 : 30 :: 39 : x = 30 \text{ and } 40 : 30 :: 39 : x = 29{\cdot}25;$$

the difference from the result in the Tables being 2 lbs. in the one case and $1\frac{3}{4}$ lb. in the other.

The following results on 10-inch tubes are also remarkably consistent with the above law.

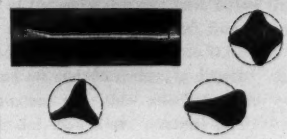
TABLE IV. Resistance of 10-inch tubes.

Mark.	No.	Diameter. inches.	Length. inches.	Thickness. inch.	Pressure of collapse. lbs. per sq. in.	Remarks.
Q.	16	10	50	·043	19	
R.	17	10	30	·043	33	

Both tubes gave way, as in the preceding experiments, with a loud report. Comparing them, we have $50:30::33:x=19{\cdot}8$; and by experiment (16.) we have 19 lbs.

Equally strong evidence in confirmation of the law respecting the lengths, will be found in the Table of 12-inch tubes. The increase of diameter, without any change in the thickness of metal, does not affect it. On the contrary, this principle of resistance, in the case of tubes with unyielding ends and open for the escape of the contained air, holds true, uniformly, throughout the whole of the experiments on 4, 6, 8, 10, and 12-inch tubes, as nearly as could be expected when due allowance is made for variations in the rigidity of the plates, imperfections in the workmanship, and difference in the tension of the sides.

TABLE V. Resistance of 12-inch tubes.

Mark.	No.	Diameter. inches.	Length. inches.	Thickness. inches.	Pressure of collapse. lbs. per sq. in.	Remarks.
S.	18	12·2	$58\frac{1}{2}$	·043	11·0	
T.	19	12·0	60	·043	12·5	
V.	20	12·0	30	·043	22·0	

Taking Experiment 20 as correct, we have for the collapsing pressure of a similar tube, 5 feet long, $60:30::22:x=11$, or 1·5 lb. less than Experiment 19. Similarly, $58\frac{1}{2}:30::22:x=11{\cdot}2$, or 0·2 lb. more than in Experiment 18. From these results we may reasonably conclude that the law affecting the strength of tubes is, other things being the same, that *the collapsing pressure varies inversely as the length.*

The tube S, when compared with the 6-inch tubes only one-half the length, required a pressure of less than one-fourth to cause collapse. This apparently low pressure, though at first sight anomalous, is confirmed by the result of Experiment 19. Similarly, comparing tubes C and D, Table I., with tubes O and P, Table III., we have,

	Length.	Diameter.	Pressure.
C and D	39	4	65
O and P	39	8	31·5;

that is, whilst the diameters are to one another as 1:2, the pressures of collapse are as 65:31·5, or as 2:1 very nearly. These comparisons, which might be continued, evidently point to a law affecting the diameters similar to that of the lengths.

In order to ascertain the different powers of resistance of tubes composed of thick plates and of different diameters, a strong tube only 9 inches in diameter, and formed of a plate $\frac{1}{4}$-inch thick, was constructed, to match and compare with another tube, also of $\frac{1}{4}$-inch plate, and $18\frac{3}{4}$-inches in diameter. The 9-inch tube was, however, found to be too strong for the retaining powers of the cylinder, which it would not have been safe to have trusted above 500 lbs. per square inch. Finding the strength of the small tube too great for the containing vessel, two new tubes were made, one with a lap-joint as at A in the annexed sketch, and another with a butt-joint as at B. These tubes were made of plates $\frac{1}{8}$th of an inch thick, the object of the difference being two-fold;—*first*, to ascertain to what extent the strength of the tube was reduced by the lap-joint; and *secondly*, to compare with the tube $18\frac{3}{4}$ inches in diameter, and double the thickness of plates. In the construction of boilers the lap-joint is almost invariably in use; and it must at once appear obvious that any such departure from the true circle in cylindrical tubes must injure their powers of resistance to external pressure.

Fig. 2.

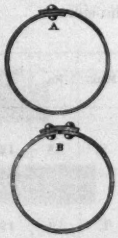
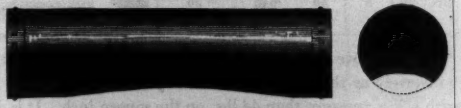


TABLE VI. Resistance of tubes with lap- and butt-joints.

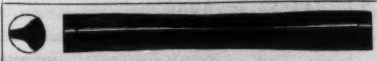
Mark.	No.	Diameter. inches.	Length. inches.	Thickness. inch.	Pressure of collapse. lbs. per. square inch.	Remarks.
W.	21	9	37	·25	(450)	Uncollapsed.
X.	22	18¾	61	·25	420	
Y.	23	9	37	·14	262	Lap-joint
Z.	24	9	37	·14	378	Butt-joint

The tube Y, Experiment 23, was made with a lap-joint, which caused it to deviate from a true circle in form, to the extent of nearly a quarter of an inch, the double thickness of the plates. In the tube Z, the cylindrical form was better maintained by the butt-joint, and this difference, apparently so small, had a serious effect upon the resisting powers of the tube. According to the results in the Table, there was a loss of more than one-third of the strength in the tube with the lap-joint, the ratio being 69·3 : 100, or 7 : 10 nearly. These facts are conclusive in showing the necessity of adhering in these constructions to the true cylindrical form.

The foregoing experiments were instituted for the purpose of ascertaining the resistance of tubes to collapse, when the ends were securely fixed to unyielding discs (as is the case with the flues of a boiler), and rigidly kept apart to prevent their approaching one another. In this position, the tubes, when submitted to severe collapsing pressures, were to some extent in a state of tension, and in some few cases, when collapse took place, the sides were torn from the cast-iron discs.

The results obtained from tubes of this construction have already been recorded, but we have yet to ascertain to what extent tubes of the same size and form follow the same laws in their resistance to external pressure when their ends are left free to approach each other. To solve this question two tubes were made, similar to those previously experimented upon, of 8 inches diameter and 60 and 30 inches in length. In these tubes there was no rigid bar down the centre, nor were they attached to the cylinder covers; they were simply placed in the cylinder, and water pumped in, in the usual manner, until they collapsed as given in the following Table:—

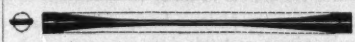
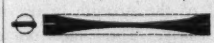
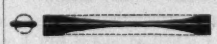
TABLE VII. Resistance of 8-inch Tubes.

Mark.	No.	Diameter. inches.	Length. inches.	Thickness.	Pressure of collapse. lbs. per sq. in.	Remarks.
AA.	25	8	60	·043	22	
BB.	26	8	30	·043	36	

In the above experiments the tubes do not appear to follow precisely the law of "inversely as the length." Had they done so, the tube BB should not have yielded with a less pressure than 44 lbs. on the square inch. It is, however, impossible to manufacture these tubes truly cylindrical, and hence it follows that slight variations may very materially affect the ultimate strength of the tube.

From three experiments on 4-inch tubes, we derive data more in accordance with the law, as will be seen below.

TABLE VIII. Resistance of 4-inch Tubes.

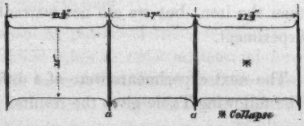
Mark.	No.	Diameter. inches.	Length. inches.	Thickness. inch.	Pressure of collapse. lbs. per sq. in.	Remarks.
CC.	27	4	60	·043	47	
DD.	28	4	30	·043	(195)	
EE.	29	4	30	·043	93	
FF.	30	4	15	·043	147	

In the above experiments, the second on tube DD is lost, in consequence of the ends being fractured and the water obtaining admission, so as to cause a counteracting pressure in the interior. Experiment 29 agrees closely with the law when compared with 27, its strength being correctly double that of the latter. The 15-inch, although not four times the strength of the 60-inch, exhibits high resisting powers. It is probably difficult to reconcile these discrepancies; but we have in these experiments sufficient data to show that these tubes also follow, in their resistance to collapse, some

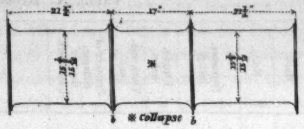
function of the length; and it is important to observe, that we cannot in practice introduce long tubes into constructions exposed to external pressure, without making very considerable allowance for their loss of strength.

In the earlier experiments the tubes were made of thin wrought-iron plates; but conceiving that it would be of interest to examine how far the laws, which were found to prevail with them, applied also to tubes of other materials, three tubes were made of the following dimensions:—

GG. Iron flue, 15 inches in diameter:—
Plates ·125 inch thick.
Web (*a a*) ·25 inch thick.
Rivets $\frac{1}{4}$ inch, at $1\frac{1}{4}$ inch apart.



HH. Steel flue, diameters $15\frac{3}{16}$ and $15\frac{5}{8}$ inches:—
Plates ·125 inch thick.
Web (*b b*) ·25 inch thick.
Rivets $\frac{1}{4}$ inch, at $1\frac{1}{4}$ inch apart.



JJ. Iron flue, with overlap joints; diameters $14\frac{1}{2}$ and $14\frac{11}{16}$ inches:—
Plates ·125 inch thick.
Ends ·25 inch thick.
Length 5 feet.
Rivets $\frac{1}{4}$ inch, at $1\frac{1}{4}$ inch apart.

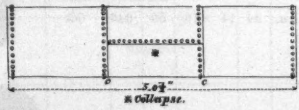


TABLE IX. Resistance of Steel and Iron Flues.

Mark.	No.	Diameters. inches.	Length. inches.	Thickness. inch.	Pressure of collapse. lbs. per sq. in.	Remarks.
GG.	31	15	21	·125	150	Each had an internal longitudinal stay between the ends.
HH.	32	$15\frac{3}{16} \times 15\frac{5}{8}$	17	·125	220	
JJ.	33	$14\frac{1}{2} \times 14\frac{11}{16}$	60	·125	125	

The experiments on these tubes do not at first sight appear to yield very satisfactory results. The first, GG, gave way with a pressure of 150 lbs. on the square inch, when it began to leak so much as to cause its removal from the vessel, to replace some of the rivets which were imperfect. After the necessary repairs, it was again subjected to experiment, when it gave way with a force of 146 lbs., showing how much it had been injured by the previous pressure. On comparing it with the mean results of all the other experiments, we find that it should have borne about 300 lbs.: it evidently failed at the rivets, and cannot be relied upon.

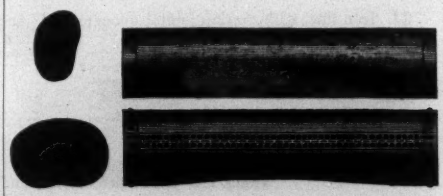
The next experimented upon was a steel tube, of the same form and with similar rigid divisions to those of the iron one. This sustained 220 lbs. on the square inch, when it bulged in or collapsed in the middle division.

The last was a plain tube of similar plates of iron, $14\frac{5}{8}$ inches in diameter, but without ribs. This collapsed with a pressure of 125 lbs. on the square inch; and this agrees nearly with the preceding experiments, as will be seen.

Comparing Experiments 32 and 33, it would appear that the steel tube is not stronger than the iron; but we are not warranted in drawing general conclusions from a single experiment.

The next experiments were of a different character, upon tubes of an elliptical form. The following Table gives the results.

TABLE X. Resistance of Elliptical Tubes.

Mark.	No.	Diameter. Inches.	Length. Inches.	Thickness. Inch.	Pressure of collapse. lbs. per square inch.	Remarks.
A*a*.	34	$14 \times 10\frac{1}{4}$	60	·043	6·5	
B*b*.	35	$20\frac{3}{4} \times 15\frac{1}{2}$	61	·250	127·5	
X.	22	$18\frac{3}{4}$	61	·250	420·0	Cylindrical.
T.	19	12	60	·043	12·5	

The last two experiments on cylindrical tubes are appended for comparison.

On comparing the elliptical tube B*b* with the cylindrical tube X, which are of the same length and thickness of plates, and only about half a square inch different in sectional area, we have for the collapsing pressure of the former 127·5 lbs., and for that of the latter 420 lbs., where it will be observed there is a loss of about $\frac{5}{7}$ths of the strength, in consequence solely of the flattening of the tube B*b*, or in other words, a cylindrical tube will support nearly three times the pressure which would collapse an elliptical tube of the same weight when proportioned like tube B*b*. A similar deficiency is observable in tube A*a*, when compared with tube T. The change of form, from the cylinder to the ellipse, where the diameter was reduced $1\frac{1}{2}$ inch in one direction and extended as much in another, reduced the bearing powers one-half. The comparative results obtained from the experiments on the thick tube are different from those on the thin

one, the loss being much greater in the former than in the latter case, although the ratio of the diameters is about the same. Allowance must, however, be made for inaccuracies of construction, though we might reasonably have expected a nearer approximation in the ratios of the deficiency of strength. From these facts, however, it is obvious that in every construction, where tubes have to sustain a uniform external pressure, the cylindrical is the only form to be relied upon, and any departure from it is attended with danger.

Resistance of Tubes to Internal Pressure.

During the investigation on the comparative resisting powers of tubes to collapse, a question arose as to the relative powers of cylindrical tubes to resist an internal force acting uniformly over their surface. It has already been demonstrated that the resistance of cylindrical vessels to internal pressure varies inversely as the diameters, but what effect the length may have upon the strength has yet to be determined. We have already seen that a cylindrical tube, when subjected to external pressure, loses one-half its strength when the length is doubled, and so on in other cases; hence arose the inquiry, what effect, if any, will an increase of length have upon a tube exposed to *internal* pressure? To solve this problem, three tubes of precisely the same diameter and thickness of plates, but of different lengths, were prepared and submitted to experiment as follows:—

TABLE XI. Resistance of Tubes to Internal Pressure.

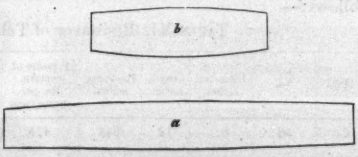
Mark.	No.	Diameter. inches.	Length. inches.	Thickness. inches.	Pressure of rupture. lbs. per square inch.	Remarks.
C*c*.	36	6	12	·043	475	
D*d*.	37	6	24	·043	235	
E*e*.	38	6	30	·043	230	[redacted]
F*f*.	39	6	48	·043	375	
G*g*.	40	12·13	60	·043	110	[redacted]

Considerable discrepancies occur in the experiments on internal pressure, as in each case the tube gave way at the riveted joint. Every precaution was taken, by carefully brazing them, to render them as nearly uniform in strength as possible. The weakness of these joints was, however, very apparent, and the results are in accordance with those arrived at several years previously, when it was found that the strengths of riveted plates were as the numbers—

100, for the solid plate;
70, for the double-riveted joint;
56, for the single-riveted joint.

This constant failure at the joints renders the experiments on internal pressure very unsatisfactory, as they do not exhibit the ultimate strength of the plate, but only the strength of the joint; and as boilers invariably present joints, these facts are probably of some significance when applied to them. On a careful examination of the fractures, that of the tube F*f* appeared the most perfect. E*e* was not so well soldered, and burst by tearing off the rivet-heads, and D*d* was torn partly through the plates and partly through the rivets; the plate of which this tube was composed was, however, exceedingly brittle, and broke like cast-iron. Tube G*g* was ruptured in the same way and in the same direction as the others; the rivets were torn through the plates, and the soldering (not very sound) was ripped up for 10 inches along the joint: this tube, as also the others, would have borne a greater pressure had the joints been more perfect and of sounder workmanship.

Comparing the tube C*c*, 1 foot long, with the tube F*f*, 4 feet long, and assuming the joints to be equally perfect in each, it would appear that there is a slight loss of strength when the length is increased; and this again suggests the question, do the rigid ends in short tubes increase the strength of the unsupported portion in proportion to the length of the tube? For example, let us take two tubes of any given diameter, the one 10 feet and the other 20 feet long; it would appear, *primâ facie*, that it was much easier to force the long tube into the form of a barrel, as at *a*, than it would be to produce the same form in the shorter tube, as at *b*; in an elastic material, such as an indian-rubber tube, the extension would certainly take place at the centre, where the particles possess diminished resistance, arising from their respective distances from the ends or points of support.



To ascertain how far this view is correct, two leaden pipes were prepared of 3 inches diameter, and of the lengths of 1 foot 2½ inches, and 2 feet 7 inches respectively, and these were submitted to the following experimental tests:—

TABLE XII. Resistance of Lead Tubes to Internal Pressure.

Mark.	No.	Diameter. inches.	Length. inches.	Thickness. inches.	Pressure of rupture. lbs. per square inch.	Remarks.	
H*h*.	41	3	14½	·25	374	At 225 lbs. pressure for H*h*, and 325 lbs. for J*j*, the ends were blown out.	
J*j*.	42	3	31	·25	364	After having been taken out and the ends replaced, they burst, as in the Table.	

The tube H*h* ruptured at the thin part of the metal, the water bursting through a

narrow slit; *Jj* ruptured similarly; and on measuring the expanded circumferences at the broadest part, it was found that the metal of the former had elongated $1\frac{1}{4}$ inch, and that of the latter $1\frac{1}{2}$ inch.

These experiments seem to show pretty conclusively, that the length has very slight influence on the resisting powers of tubes of *wrought iron* to internal pressure. Beyond the limit of one or two feet in length, it appears to affect the strength so slightly, that it may be almost entirely disregarded in practice.

GENERALIZATION OF THE RESULTS OF THE EXPERIMENTS.

In the reduction of the experiments, I have, as on former occasions, been ably assisted by my friend Mr. TATE, whose sound philosophical views and high mathematical attainments are, from his numerous publications, so well known to the public. To that gentleman I am indebted for many services, and among others for an elaborate inquiry into the specific gravity and properties of steam, which I hope will be shortly forthcoming as a new addition to our knowledge, and that more particularly in its application to the wants and necessities of the present high state of civilization.

On this question I am personally gratified to find the subject in such able hands, and aided by the industry, care and perseverance of my own assistant, Mr. W. UNWIN, I entertain hopes of rendering the researches now in progress of such a character as fully to justify the application of the word *useful*, which of all others is probably the best calculated to express the true value of these investigations.

Formulæ of Strength relative to Cylindrical Tubes.

The strain which the material of a cylindrical vessel undergoes, when a uniformly-distributed external pressure is applied to it, is very different from the strain produced when the pressure acts internally. In the latter case the material is equally extended throughout all its parts, and its cylindrical form is preserved at all stages of the pressure, with the exception of a small portion closely bordering upon the inflexible plates closing the extremities. The tube under a high internal pressure will assume the form represented in the annexed diagram, and the relation of the force of rupture to that of resistance will be approximately expressed by

$$P = \frac{2E \times k}{D}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1.)$$

where P represents the pressure requisite to produce rupture, E the ultimate resistance of the material to extension, D the diameter of the tube, and k its thickness; whereas in the former case, the material, being compressed, becomes crumpled in longitudinal lines near the middle; the tube loses its original cylindrical shape at and near to that part, whilst the portions towards the extremities being supported by the inflexible end plates, retain, or nearly retain, their original form; so that, in fact, the material virtually resisting compression is the comparatively small portion at and near the middle, and

which, to a certain extent, is independent of the length of the tube, whilst the pressure producing the compression is always approximately proportional to the longitudinal section. Now let us assume for these tubes,—

P' = the external pressure of the fluid in lbs. to produce rupture or collapse;
P = this pressure per square inch;
R = the resistance of the material to compression or to crumpling;
L = the length of the tube in feet;
D = the diameter of the tube in inches;
k = the thickness of the plates in inches;
p = the pressure P reduced to unity of length and diameter, or $=PLD$;
C, α, constants to be determined from the data supplied by the experiments.

Since P', the total pressure on the tube, varies directly as the longitudinal section, that is, as the product of the length by the diameter, we have

$$P'=C'.P.L.D.$$

Now it has been determined by experiment, that the resistance of thin iron plates to a force tending to crush them, or rather to a force tending to crumple them, varies directly as a certain power of their thickness, the number indicating the power lying between 2 and 3; hence we assume,

$$R=C''.k^{\alpha};$$

but when rupture takes place, $P'=R$, and

$$C'.P.L.D=C''.k^{\alpha},$$

$$\therefore \quad P=\frac{Ck^{\alpha}}{LD}. \quad \ldots \ldots \ldots \ldots \quad (2.)$$

For tubes of the same thickness, we readily derive from this equality,

$$P.L.D=P_{\prime}.L_{\prime}.D_{\prime}; \quad \ldots \ldots \ldots \ldots \quad (3.)$$

that is, the continued product of the pressure, the length and the diameter is constant; or in other words, for tubes having the same thickness, the pressures of collapse reduced to unity of length and diameter (p) are equal to one another.

To determine the values of the constants α and C in (2.), we have

$$\frac{PLD}{P_{\prime}L_{\prime}D_{\prime}}=\left(\frac{k}{k_{\prime}}\right)^{\alpha}.$$

But in order to embrace a range of experiments by taking the mean of their results, we have, putting p for the value of P, when the tube is reduced to unity of length and to unity of diameter,

$$\frac{p}{p_{\prime}}=\left(\frac{k}{k_{\prime}}\right)^{\alpha},$$

$$\therefore \quad \alpha=\frac{\log p-\log p_{\prime}}{\log k-\log k_{\prime}}; \quad \ldots \ldots \ldots \ldots \quad (4.)$$

and similarly, we find

$$C=\frac{p}{k^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5.)$$

A glance at the results of the experiments recorded in Tables I. II. III. IV. V., where the thickness of the plates composing the tubes is the same, is sufficient to show, —1st, that the strength of the tubes varies nearly inversely as their lengths; 2ndly, that the strength also varies nearly inversely as the diameters. The following reduction of these experiments will not only render these laws apparent, but will also show that in tubes of the same thickness the strength varies inversely as the product of their lengths by their diameters, or, what amounts to the same thing, that PLD ($=p$) is nearly a constant quantity.

Reduction of the Results of the Experiments on the Collapse of Sheet-iron Tubes ·043 inch thick, to unity of length and diameter.

Experiments 1, 2 and 6, were performed on tubes of the same length and diameter, and also Experiments 7, 10 and 11; hence we have for the mean values of P,—

$$\text{Mean value of P from Experiments 1, 2 and 6}=\frac{170+137+140}{3}=149.$$

$$\text{Mean value of P from Experiments 7, 10 and 11}=\frac{48+52+65}{3}=55.$$

4-inch Tubes.

No. of experiment.	D. Diameter in inches.	L. Length in feet.	P. Pressure of collapse in lbs.	P. L. Pressure reduced to unity of L.	P. D. Pressure reduced to unity of D.	p. Pressure reduced to unity of L and D.
1, 2, 6	4	$1\frac{7}{12}$	149	232·5	596	930·0
3	4	$3\frac{1}{2}$	65	216·6	260	866·4
4	4	$3\frac{1}{6}$	65	205·8	260	823·2
5	4	5	43	215·8	172	860·0
27	4	5	47	235·0	188	940·0
29	4	$2\frac{1}{2}$	93	232·5	372	930·0

6)5349·6

Mean value of p..... 891·6

The approximation of the numbers to one another in columns 5 and 7, shows how very nearly the strength varies inversely as the lengths. This observation applies with equal exactness to all the reductions which follow.

6-inch Tubes.

No. of experiment.	D.	L.	P.	P. L.	P. D.	p.
7, 10, 11	6	$2\frac{1}{2}$	55	137·5	330	825
9	6	$4\frac{11}{12}$	32	157·3	192	944

2)1769

Mean value of p ... 884·5

8-inch Tubes.

No. of experiment.	D.	L.	P.	P. L.	P. D.	p.
13	8	$2\frac{1}{2}$	39	97·5	312	780·0
14	8	$3\frac{1}{4}$	32	104·0	256	832·0
15	8	$3\frac{1}{3}$	31	103·3	248	826·4

3)2438·4

Mean value of p ... 812·8

10-inch Tubes.

No. of experiment.	D.	L.	P.	P. L.	P. D.	p.
16	10	$4\frac{1}{2}$	19	79·1	190	791
17	10	$2\frac{1}{2}$	36	90·0	360	900

2)1691

Mean value of p ..... 845·5

A comparison of the numbers in the sixth columns with the numbers given by the experiments on tubes of the same length, clearly shows that the strength varies very nearly in the inverse ratio of the diameters; and moreover, since the mean values of p for the different sets of tubes nearly coincide with one another, we infer that the strength varies inversely as the product of the length by the diameter, or that $p=\mathrm{PLD}=$ a constant.

12-inch Tubes.

No. of experiment.	D.	L.	P.	P. L.	P. D.	p.
18	12·2	$4\frac{11}{21}$	11·0	53·6	123·2	654
19	12	5	12·5	62·5	150·0	750
20	12	$2\frac{1}{2}$	22·0	55·0	264·0	660

3)2064

Mean value of p..... 688

Here the mean value of p is somewhat below the value determined from the other tubes. This discrepancy is no doubt owing to the difficulty there is in maintaining such thin tubes of large diameter exactly in the cylindrical form. This circumstance seems to suggest that a small correction, depending on the ratio of the diameter of the tube to its thickness, may be requisite to render formula (2.) mathematically exact. This correction will assume the form of $-\mathrm{E}\times\frac{\mathrm{D}}{k}$, where the constant E remains to be determined from the data of the experiments.

Mean value of p *derived from the foregoing results.*

$$p=\tfrac{1}{5}\{891\cdot6+884\cdot5+812\cdot8+845\cdot5+688\}=824.$$

Reduction of the Results of Experiments 22, 24, 33 on the Collapse of Sheet-iron Tubes to unity of length and diameter.

No. of experiment.	D.	L.	k. Thickness.	P.	p.
22	$18\frac{3}{4}$	$5\frac{1}{12}$	·25	420	40,030
24	9	$3\frac{1}{12}$	·14	378	10,495
33	$14\frac{5}{8}$	5	·125	125	9,140

To find the Value of the Constants α *and* C *in the General Formula.*

In equality (4.), taking $p=40{,}030$, $k=\cdot25$, $p_{\prime}=820$, $k_{\prime}=\cdot043$; we get

$$\alpha=\frac{\log 40{,}030-\log 820}{\log\cdot25-\log\cdot043}=2\cdot23.$$

Similarly, taking $p=40{,}030$, $k=\cdot25$, $p_{\prime}=9140$, and $k_{\prime}=\cdot125$; we get

$$\alpha=\frac{\log 40{,}030-\log 9140}{\log\cdot25-\log\cdot125}=2\cdot14;$$

and taking $p=10{,}495$, $k=\cdot14$, $p_{\prime}=820$, $k_{\prime}=\cdot043$; we get

$$\alpha=\frac{\log 10{,}495-\log 820}{\log\cdot14-\log\cdot043}=2\cdot16;$$

and taking the mean of these values, we get $\alpha=2\cdot19$.

For the value of the constant C, we have from (5.),

$$C=\frac{p}{k^{\alpha}}=\frac{820}{\cdot043^{2\cdot19}}=806{,}300.$$

Substituting these values in (2.), we get

$$P=806{,}300\times\frac{k^{2\cdot19}}{LD}, \quad\ldots\ldots\ldots\ldots \quad (6.)$$

which is the general formula for calculating the strength of wrought-iron tubes subjected to external pressure*, within the limits indicated by the experiments; that is, provided their length is not less than 1·5 foot, and not greater probably than 10 feet.

In order to facilitate calculation, formula (6.) may be written,

$$\log P=1\cdot5265+2\cdot19\log 100\,k-\log(LD);$$

* By taking 2 instead of 2·19 for the index of k, this formula becomes

$$P=806{,}300\times\frac{k^2}{L.D}, \quad\ldots\ldots\ldots\ldots \quad (a.)$$

whence the value of P, the collapsing pressure may be readily calculated by ordinary arithmetic.

For thick tubes of considerable diameter and length, this formula may be regarded as sufficiently exact for practical purposes.

For example, let $k=\frac{1}{8}$ inch, L=10 feet, D=36 inches; then

$$P=806{,}300\times\frac{(\frac{1}{8})^2}{10\times36}=560\text{ lbs.}$$

By formula (6.), $-P=1\cdot5265+2\cdot19\log 50-\log 360=502$ lbs.

It will be observed that these results do not differ widely from each other.

and by an obvious transformation, we have

$$P=\frac{820}{L.D}.$$

The following Table will show how nearly formula (6.) represents the results of the experiments on the different classes of tubes.

No. of experiment.	D. Diameter. inches.	L. Length. feet.	k. Thickness. inches.	P. By experiment in lbs.	P. By formula (6.).	Proportional error by formula
2	4	$1\frac{7}{12}$	·043	137	130	$-\frac{1}{19}$
5	4	5	·043	43	41	$-\frac{1}{22}$
7, 10, 11	6	$2\frac{1}{2}$	·043	55	54·7	$-\frac{1}{200}$
14	8	$3\frac{1}{4}$	·043	32	31·6	$-\frac{1}{80}$
16	10	$4\frac{1}{8}$	·043	19	19·7	$+\frac{1}{30}$
19	12	5	·043	12·5	13·6	$+\frac{1}{12}$
23	$18\frac{3}{4}$	$5\frac{1}{12}$	·250	420	407	$-\frac{1}{32}$
26	9	$3\frac{1}{12}$	·140	378	392	$+\frac{1}{27}$
33	$14\frac{5}{8}$	5	·125	125	116	$-\frac{1}{18}$

So far as regards practical purposes, this formula appears to possess every desirable precision. As already anticipated, the results derived from the thin 12-inch tubes present the greatest deviation. The value of P, derived from the following formula, gives a still closer approximation to the results of the experiments, viz.—

$$P=806{,}300\times\frac{k^{2\cdot19}}{L.D}-\cdot002\times\frac{D}{k}.$$

It is highly desirable that we should verify the law $P.L.D=P_{\prime}.L_{\prime}.D_{\prime}$, as applied to thick tubes. Now, we know the value of α independently of these experiments, for its value, as determined above, closely approximates to the value derived from the experiments on the compression of sheet-iron plates. Let us, therefore, reduce the collapsing pressure of these plates to unity of thickness, with the view of ascertaining the law of variation of pressure as regards length and diameter.

Let P be the pressure of collapse of a tube k inches thick, and P′ the pressure when the tube is ·1 inch thick; then

$$\frac{P'}{P}=\left(\frac{\cdot1}{k}\right)^{\alpha},$$

$$\therefore\quad P'=P\times\left(\frac{1}{10k}\right)^{\alpha}=\frac{P}{(10k)^{\alpha}},$$

and

$$\log P'=\log P-2\cdot19\log(10k).$$

Reducing the values of P by this formula, we derive the following results:—

No. of experiment.	D. Diameter.	L. Length.	k. Thickness.	P. Pressure.	P′, or value of P reduced to unity of thickness, viz. ·1.	Value of P′. L. D.
5	4	5	·043	43	273	5400
22	$18\frac{3}{4}$	$5\frac{1}{12}$	·250	420	57	5400
24	9	$3\frac{1}{12}$	·140	378	190	5300
33	$14\frac{1}{2}$	5	·125	125	76	5600

The remarkable approximation of the numbers in the last column to one another, distinctly establishes the law ($P.L.D=P_{\prime}.L_{\prime}.D_{\prime}$) in relation to tubes composed of thick plates.

Deduction from the Results of the Experiments on the Collapse of Elliptical Tubes.

By comparing the result of experiment (34.) on the elliptical tube with the result of the experiments on the cylindrical tubes, we find that the general formula (6.) will apply approximately to elliptical tubes, by substituting for D in that formula the diameter of the circle of curvature touching the extremity of the minor axis. Thus we have,

$$\text{Diameter of the circle of curvature} = \frac{2a^2}{b} = \frac{2 \times 7^2}{5} = 20 \text{ nearly.}$$

Now the pressure on this elliptical tube was 6·5 lbs., which reduced to unity of length and diameter, gives 650 lbs., which result nearly agrees with 688 lbs., the mean pressure of the 12-inch tubes also reduced to unity of length and diameter.

Although this deduction is based on merely one experimental result, yet it appears to be confirmed by the following proposition derived from mathematical analysis.

The pressure P per square inch, requisite to flatten equal angular portions of a tube of variable curvature, varies inversely as the diameters of curvature.

Hence it will be observed how very much the strength of a tube subjected to external pressure is deteriorated by a deviation from the cylindrical form.

Strength of Cylindrical Tubes subjected to Internal Pressure.

Taking the mean of the results of Experiments 36 and 39 on iron tubes, we have from formula

$$E = \frac{425 \times 6}{2 \times \cdot 043} = 30{,}000 \text{ nearly.}$$

Hence we find

$$P = \frac{60{,}000\,k}{D}, \quad \ldots \ldots \ldots \ldots \quad (7.)$$

which gives the formula of strength of thin sheet-iron tubes subjected to internal pressure.

Now the tenacity of boiler plates has been found to be 23 tons, or 51,520 lbs. per

square inch; hence it appears that a considerable reduction of tenacity must be made for the riveting of the plates. The ratio of reduction is in this case $\frac{3}{8}$.

One remarkable fact distinctly established by these experiments, is the comparative weakness of tubes subjected to external pressure. If p be put for the internal pressure per square inch at which a tube is ruptured, then for tubes of the same thickness and diameter, we find from (6.) and (7.) the following relation of strength:—

$$\frac{p}{P}=\frac{1}{13{\cdot}44}\times\frac{L}{k^{1{\cdot}19}}$$

If $L=2\frac{1}{2}$ and $k={\cdot}043$, then $\frac{p}{P}=7{\cdot}77$; that is to say, in this case the tube subjected to internal pressure will have about $7\frac{1}{2}$ times the strength of a similar tube subjected to external pressure. When

$$p=P,$$

we find

$$L=13{\cdot}44k^{1{\cdot}19}.$$

If $k={\cdot}25$, then we find $L=3\frac{3}{4}$ feet nearly; that is, a tube of this length and thickness will be equally strong whether subjected to external or internal pressure.

Taking the mean of Experiments 41 and 42 on the lead pipes, we have from formula (1.),

$$E=\frac{370\times 3}{2\times{\cdot}25}=2220,$$

which gives us the tenacity of lead per square inch.

Hence we find

$$P=\frac{4440k}{D}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8.)$$

which gives the formula of strength of lead tubes subjected to an internal pressure.

Practical Application to Construction of the Results of the Experiments.

Throughout the whole of the experiments enumerated in the preceding pages, it has been proved that the resistance to collapse from a uniform external pressure, in cylindrical tubes, varies in the inverse ratio of the lengths. This law has been tested to lengths not exceeding fifteen diameters of the tube; but the point at which it ceases to hold true is as yet undetermined, and could only be ascertained by a new and laborious series of experiments on tubes of considerably greater length, in which the strength of the material modifies the above law of resistance to collapse. Such experiments are, doubtless, very desirable; but the vessels necessary for the purpose would be most expensive, and the results already obtained appear to supply all the data necessary for calculating the strengths and proportioning the material in all ordinary cases.

If we take a boiler of the ordinary construction, 30 feet long and 7 feet in diameter, with one or more flues 3 feet or 3 feet 6 inches in diameter, we find that the cylindrical external shell is from three to four times stronger in its powers of resistance to the force tending to burst it, than the flues are to resist the same force tending to collapse them. This being the case in boilers of ordinary construction, it is not surprising that so many

fatal accidents should have occurred from the collapse of the internal flues, followed immediately by the explosion and rupture of the outer shell. To remedy such evils, and to place the security of vessels so important to the community upon a more certain basis, it is essential that every part should be of *uniform strength* to resist the forces brought to bear upon it. The equalization of the powers of resistance is the more important, as the increased strength of the outer shell is absolutely of no value, so long as the internal flues remain, as at present, liable to be destroyed by collapse, at a pressure of only one-third of that required to burst the envelope which surrounds them.

The following Table, deduced from my own experiments, exhibits the safe working pressure, and the bursting pressure of boilers of different diameters, calculated for an external shell of a thickness of $\frac{3}{8}$ths of an inch.

Diameter of boiler.		Working pressure.	Bursting pressure.
ft.	in.	lbs.	lbs.
3	0	118	708¼
3	6	101	607
4	0	88½	531
4	6	78¾	472
5	0	70¾	425
5	6	64¾	386¼
6	0	59	354
6	6	54¼	326¾
7	0	50½	303½
7	6	47	283¼
8	0	44	265¼
8	6	41½	250

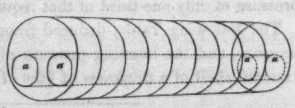
Taking from the above Table the strength of a boiler 7 feet in diameter, we find its bursting pressure to be 303 lbs. per square inch. For such a boiler the flues would be ordinarily 3 feet in diameter, and of the same thickness of plates as the shell; and by the formula, $\log P = 1{\cdot}5265 + 2{\cdot}19 \log 100k - \log (\text{L.D.})$, we obtain for their collapsing pressure 87 lbs. per square inch. As, however, the formula does not apply with strictness to tubes of such length, the actual collapsing pressure will be somewhat greater than this. The immense excess of strength in the outer shell is, however, sufficiently apparent; the extra thickness of boiler plate which causes it being so much material thrown away, adding nothing to the strength whilst the flues remain in so dangerously weak a condition.

To meet this disparity of strength, the experiments indicate the necessity of *shorter* flues, and one of them shows how this may be obtained, practically and efficiently, without interfering with the present construction of boilers. In Experiment 6, Table I., the tube F was divided into three parts by two rigid rings soldered upon its exterior, and its powers of resistance were thus increased in the ratio of three to one; *virtually*, the length was reduced in this ratio, and the strength was *actually* increased from 43 to 140 lbs. per square inch.

It is proposed to apply a similar construction to the flues of boilers, to equalize their powers of resistance with those of the outer shell, on the supposition that the law of

decrease of strength holds true, within no great limits of error, to tubes of much greater length than in the preceding experiments. That this conclusion is not empirical, will be seen by the following experiments upon boilers of full size, where it will be observed that the flues were distorted with one-third the pressure required to rupture the external shell.

These boilers were made for the North-Eastern Division of the London and North-Western Railway Company, and were respectively of 35 and 25 feet in length. They were 7 feet in diameter, and composed of plates $\frac{3}{8}$ths of an inch thick. Each boiler had two cylindrical flues 3 feet 6 inches in diameter, and of the same thickness of plates as the outer shell. They were fixed in the position shown in the annexed diagram, and were intended to resist an ordinary working pressure of only 40 lbs. upon the square inch. In submitting them to the usual test of double pressure, the flues of the first or longest boiler gave way with 97 lbs. upon the square inch; and those of the shorter boiler required 127 lbs. to effect the same distortion. With these large tubes a complete collapse was not accomplished, but the circular form, indicated by the dotted line, was *distorted*, and the flue became elliptical, as shown at *b b**.



The weakness of the flues in the above experiments is so evident as to need no comment. To remedy it, it has been already stated, we need only resort to a construction so simple, and yet so effective, as to meet at a small expense all the requirements of the case.

* Reducing the above results to unity of length, which with flues of this size should give a nearly constant quantity, we have—

	D.	L.	P.	P.L.
First boiler	42	35	97	3395
Second boiler	42	25	127	3175

The correspondence in the last column shows that these flues obey the law of inversely as the lengths, very nearly, in their powers of resistance.

It may be well to test the accuracy of the formula which has been found to apply to tubes of a length not greater than 10 feet, by determining from it the strength of flues similar to the above, and comparing the results with those derived from experiment.

Here, for the boiler 35 feet long, we have by formula

$$P=806{,}300\frac{k^2}{LD.},$$

$$=78 \text{ lbs.}; \text{ by experiment } 97 \text{ lbs.}$$

This difference confirms the view already stated, that the formula for short tubes does not apply *strictly* to tubes longer than 10 feet.

For the boiler 25 feet long, we have

$$P=109 \text{ lbs.}; \text{ by experiment } 127 \text{ lbs.}$$

A less difference between the experimental and calculated result, as would have been anticipated from the shorter length of the flue.

It will be observed, that even these experiments, upon full-sized boilers, are remarkably consistent, and offer no discrepancies which cannot be easily explained consistently with the general formula.

Figure 1, Plate XXIX., exhibits an ordinary boiler flue, 30 feet long and 2 feet 9 inches in diameter, with simple lap-joints, as hitherto invariably constructed. To attain nearly three times the strength of this, it will only be necessary to introduce two strong, rigid, angle-iron ribs, as exhibited in figs. 2 and 3, at *a*, *a*. This arrangement will not only remove all doubts as to the strength of these flues, by bringing them within the limits to which the formula applies with strictness, but will give to flues 30 feet long a strength equivalent to that of flues only 10 feet long, and make them uniform in their powers of resistance with the other parts of the boiler.

The reduction of the strength of flues by the lap-joints has already been stated; the deviation from the true cylindrical form which they cause, lessens, in some cases, seriously the strength of the vessels, as may be seen in Experiments 23 and 24, Table VI. Hence it is also proposed that flues required to resist an external pressure should be formed with double-riveted *butt-joints*, with longitudinal covering plates, as shown at *b*, *b*, *b*, fig. 3, Plate XXIX. It is believed that these alterations will secure ample safety in these important constructions, and in this trust they are commended to the attention of the engineer and the public generally.

XXII. *A Fourth Memoir upon Quantics.* By ARTHUR CAYLEY, *Esq.*, *F.R.S.*

Received February 11,—Read March 18, 1858.

THE object of the present memoir is the further development of the theory of binary quantics; it should therefore have preceded so much of my third memoir, t. 147 (1857), p. 627, as relates to ternary quadrics and cubics. The paragraphs are numbered continuously with those of the former memoirs. The first three paragraphs, Nos. 62 to 64, relate to quantics of the general form $(*\between x, y, ..)^m$, and they are intended to complete the series of definitions and explanations given in Nos. 54 to 61 of my third memoir; Nos. 68 to 71, although introduced in reference to binary quantics, relate or may be considered as relating to quantics of the like general form. But with these exceptions the memoir relates to binary quantics of any order whatever: viz. No. 65 to 80 relate to the covariants and invariants of the degrees 2, 3 and 4; Nos. 81 and 82 (which are introduced somewhat parenthetically) contain the explanation of a process for the calculation of the invariant called the Discriminant; Nos. 83 to 85 contain the definitions of the Catalecticant, the Lambdaic and the Canonisant, which are functions occurring in Professor SYLVESTER's theory of the reduction of a binary quantic to its canonical form; and Nos. 86 to 91 contain the definitions of certain covariants or other derivatives connected with BEZOUT's abbreviated method of elimination, due for the most part to Professor SYLVESTER, and which are called Bezoutiants, Cobezoutiants, &c. I have not in the present memoir in any wise considered the theories to which the catalecticant, &c. and the last-mentioned other covariants and derivatives relate; the design is to point out and precisely define the different covariants or other derivatives which have hitherto presented themselves in theories relating to binary quantics, and so to complete, as far as may be, the explanation of the terminology of this part of the subject.

62. If we consider a quantic

$$(a, b, ..\between x, y, ...)^m$$

and an adjoint linear form, the operative quantic

$$(a, b, ..\between \partial_\xi, \partial_\eta, ..)^m,$$

or more generally the operative quantic obtained by replacing in any covariant of the given quantic the facients $(x, y, ..)$ by the symbols of differentiation $(\partial_\xi, \partial_\eta, ...)$ (which operative quantic is, so to speak, a contravariant operator), may be termed the *Provector*; and the Provector operating upon any contravariant gives rise to a contravariant, which may of course be an invariant. Any such contravariant, or rather such contravariant considered as so generated, may be termed a *Provectant*; and in like manner the operative quantic obtained by replacing in any contravariant of the given quantic

the facients $(\xi, \eta ..)$ by the symbols of differentiation $(\partial_x, \partial_y, \ldots)$ (which operative quantic is a covariant operator), is termed the *Contraprovector*; and the contraprovector operating upon any covariant gives rise to a covariant, which may of course be an invariant. Any such covariant, or rather such covariant considered as so generated, may be termed a *Contraprovectant*.

In the case of a binary quantic,

$$(a, b, ..\between x, y)^m,$$

the two theorems coalesce together, and we may say that the operative quantic

$$(a, b, ..\between \partial_y, -\partial_x)^m,$$

or more generally the operative quantic obtained by replacing in any covariant of the given quantic the facients (x, y) by the symbols of differentiation $(\partial_y, -\partial_x)$ (which is in this case a covariant operator), may be termed the Provector. And the Provector operating on any covariant gives a covariant (which as before may be an invariant), and which considered as so generated may be termed the Provectant.

63. But there is another allied theory. If in the quantic itself or in any covariant we replace the facients $(x, y, \ldots)$ by the first derived functions $(\partial_\xi P, \partial_\eta P \ldots)$ of any contravariant P of the quantic, we have a new function which will be a contravariant of the quantic. In particular, if in the quantic itself we replace the facients $(x, y \ldots)$ by the first derived functions $(\partial_\xi P, \partial_\eta P, ..)$ of the Reciprocant, then the result will contain as a factor the Reciprocant, and the other factor will be also a contravariant. And similarly, if in any contravariant we replace the facients $(\xi, \eta, ..)$ by the first derived functions $(\partial_x W, \partial_y W, ..)$ of any covariant W (which may be the quantic itself) of the quantic U, we have a new function which will be a covariant of the quantic. And in particular if in the Reciprocant we replace the facients $(\xi, \eta, \ldots)$ by the first derived functions $(\partial_x U, \partial_y U ..)$ of the quantic, the result will contain U as a factor, and the other factor will be also a covariant. In the case of a binary quantic $(a, b, ..\between x, y)^m$ the two theorems coalesce and we have the following theorem, viz. if in the quantic U or any covariant the facients (x, y) are replaced by the first derived functions $(\partial_y W, -\partial_x W)$ of a covariant W, the result will be a covariant; and if in the quantic U the facients (x, y) are replaced by the first derived functions $(\partial_y U, -\partial_x U)$ of the quantic, the result will contain U as a factor, and the other factor will be also a covariant.

Without defining more precisely, we may say that the function obtained by replacing as above the facients of a covariant or contravariant by the first derived functions of a contravariant or covariant is a *Transmutant* of the first-mentioned covariant or contravariant.

64. Imagine any two quantics of the same order, for instance, the two quantics

$$U = (a, b, \ldots \between x, y ..)^m,$$
$$V = (a', b', \ldots \between x, y ..)^m,$$

then any quantic such as $\lambda U + \mu V$ may be termed an *Intermediate* of the two quantics;

and a covariant of $\lambda U+\mu V$, if in such covariant we treat λ, μ as facients, will be a quantic of the form

$$(A, B, .. B', A')(\lambda, \mu)^n,$$

where the coefficients (A, B, .. B', A') will be covariants of the quantics U, V, viz. A will be a covariant of the quantic U alone; A' will be the same covariant of the quantic V alone, and the other coefficients (which in reference to A, A' may be termed the *Connectives*) will be covariants of the two quantics; and any coefficient may be obtained from the one which precedes it by operating on such preceding coefficient with the combinantive operator

$$a'\partial_a+b'\partial_b+\ldots,$$

or from the one which succeeds it by operating on such succeeding coefficient with the combinantive operator

$$a\partial_{a'}+b\partial_{b'}+\ldots$$

the result being divided by a numerical coefficient which is greater by unity than the index of μ or (as the case may be) λ in the term corresponding to the coefficient operated upon. It may be added, that any invariant in regard to the facients (λ, μ) of the quantic

$$(A, B, ..B', A')(\lambda, \mu)^n$$

is not only a covariant, but it is also a combinant of the two quantics U, V.

As an example, suppose the quantics U, V are the quadrics

$$(a, b, c)(x, y)^2 \text{ and } (a', b', c')(x, y)^2,$$

then the quadrinvariant of

$$\lambda U+\mu V \text{ is } (\lambda a+\mu a')(\lambda c+\mu c')-(\lambda b+\mu b')^2,$$

which is equal to

$$(ac-b^2,\ ac'-2bb'+ca',\ a'c'-b'^2)(\lambda, \mu)^2,$$

and $ac'-2bb'+ca'$ is the connective of the two discriminants $ac-b^2$ and $a'c'-b'^2$.

65. The law of reciprocity for the number of the invariants of a binary quantic*, leads at once to the theorems in regard to the number of the quadrinvariants, cubinvariants and quartinvariants of a binary quantic of a given degree, first obtained by the method in the second part of my original memoir†. Thus a quadric has only a single invariant, which is of the degree 2; hence, by the law of reciprocity, the number of quadrinvariants of a quantic of the order m is equal to the number of ways in which m can be made up with the part 2, which is of course unity or zero, according as m is even or odd. And we conclude that

The quadrinvariant exists only for quantics of an even order, and for each such quantic there is one, and only one, quadrinvariant.

66. Again, a cubic has only one invariant, which is of the degree 4, and the number of cubinvariants of a quantic of the degree m is equal to the number of ways in which m can be made up with the part 4. Hence

* Introd. Memoir, No. 20. † Ibid. Nos. 10–17.

A cubinvariant only exists for quantics of an evenly even order, and for each such quantic there is one, and only one, cubinvariant.

67. But a quartic has two invariants, which are of the degrees 2 and 3 respectively, and the number of quartinvariants of a quantic of the degree m is equal to the number of ways in which m can be made up with the parts 2 and 3. When m is even, there is of course a quartinvariant which is the square of the quadrinvariant, and which, if we attend only to the irreducible quartinvariants, must be excluded from consideration. The preceding number must therefore, when m is even, be diminished by unity. The result is easily found to be

Quartinvariants exist for a quantic of any order, even or odd, whatever, the quadric and the quartic alone excepted; and according as the order of the quantic is

$$6g,\quad 6g+1,\quad 6g+2,\quad 6g+3,\quad 6g+4,\quad 6g+5,$$

the number of quartinvariants is

$$g,\quad g\ ,\quad g\ ,\quad g+1,\quad g\ ,\quad g+1.$$

In particular, for the orders

$$2,\ 3,\ 4,\ 5;\ 6,\ 7,\ 8,\ 9,\ 10,\ 11;\ 12, \&c.,$$

the numbers are

$$0,\ 1,\ 0,\ 1;\ 1,\ 1,\ 1,\ 2,\ 1,\ 2;\ 2, \&c.$$

So that the nonic is the lowest quantic which has more than one quartinvariant.

68. But the whole theory of the invariants or covariants of the degrees 2, 3, 4 is most easily treated by the method above alluded to, contained in the second part of my original memoir; and indeed the method appears to be the appropriate one for the treatment of the theory of the invariants or covariants of any given degree whatever, although the application of it becomes difficult when the degree exceeds 4. I remark, in regard to this method, that it leads naturally, and in the first instance, to a special class of the covariants of a system of quantics, viz. these covariants are linear functions of the derived functions of any quantic of the system. (It is hardly necessary to remark that the derived functions referred to are the derived functions of any order of the quantic with regard to the facients.) Such covariants may be termed *tantipartite* covariants; but when there are only two quantics, I use in general the term *lineo-linear*. The tantipartite covariants, while the system remains general, are a special class of covariants, but by particularizing the system we obtain all the covariants of the particularized system. The ordinary case is when all the quantics of the system reduce themselves to one and the same quantic, and the method then gives all the covariants of such single quantic. And while the order of the quantic remains indefinite, the method gives covariants (not invariants); but by particularizing the order of the quantic in such manner that the derived functions become simply the coefficients of the quantic, the covariants become invariants: the like applies of course to a system of two or more quantics.

69. To take the simplest example, in seeking for the covariants of a single quantic U, we in fact have to consider two quantics U, V. An expression such as $\overline{12}\,\mathrm{UV}$ is a lineo-linear covariant of the two quantics; its developed expression is

$$\partial_x \mathrm{U}.\partial_y \mathrm{V} - \partial_y \mathrm{U}.\partial_x \mathrm{V},$$

which is the Jacobian. In the particular case of two linear functions $(a, b \between x, y)$ and $(a', b' \between x, y)$, the lineo-linear covariant becomes the lineo-linear invariant $ab' - a'b$, which is the Jacobian of the two linear functions.

In the example we cannot descend from the two quantics U, V to the single quantic U (for putting $\mathrm{V} = \mathrm{U}$ the covariant vanishes); but this is merely accidental, as appears by considering a different lineo-linear covariant $\overline{12}^2\mathrm{UV}$, the developed expression of which is

$$\partial_x^2 \mathrm{U}.\partial_y^2 \mathrm{V} - 2\partial_x\partial_y \mathrm{U}.\partial_x\partial_y \mathrm{V} + \partial_y^2 \mathrm{U}.\partial_x^2 \mathrm{V}.$$

In the particular case of two quadrics $(a, b, c \between x, y)^2$, $(a', b', c' \between x, y)^2$, the lineo-linear covariant becomes the lineo-linear invariant

$$ac' - 2bb' + ca'.$$

If we have $\mathrm{V} = \mathrm{U}$, then the lineo-linear covariant gives the quadricovariant

$$\partial_x^2 \mathrm{U}.\partial_y^2 \mathrm{U} - (\partial_x\partial_y \mathrm{U})^2$$

of the single quantic U (such quadricovariant is in fact the Hessian); and if in the last-mentioned formula we put for U the quadric $(a, b, c \between x, y)^2$, or what is the same thing, if in the expression of the lineo-linear invariant $ac' - 2bb' + ca'$, we put the two quadrics equal to each other, we have the quadrinvariant

$$ac - b^2$$

of the single quadric.

70. The lineo-linear invariant $ab' - a'b$ of two linear functions may be considered as giving the lineo-linear covariant $\partial_x \mathrm{U}.\partial_y \mathrm{V} - \partial_y \mathrm{U}.\partial_x \mathrm{V}$ of the two quantics U and V, and in like manner the lineo-linear invariant $ac' - 2bb' + ca'$ may be considered as giving the lineo-linear covariant $\partial_x^2 \mathrm{U}.\partial_y^2 \mathrm{V} - 2\partial_x\partial_y \mathrm{U}.\partial_x\partial_y \mathrm{V} + \partial_y^2 \mathrm{U}.\partial_x^2 \mathrm{V}$ of the quantics U, V. And generally, any invariant whatever of a quantic or quantics of a given order or orders leads to a covariant of a quantic or quantics of any higher order or orders: viz. the coefficients of the original quantic or quantics are to be replaced by the derived functions of the quantic or quantics of a higher order or orders.

71. The same thing may be seen by means of the theory of Emanants. In fact, consider any emanants whatever of a quantic or quantics; then, attending only to the facients of emanation, the emanants will constitute a system of quantics the coefficients of which are derived functions of the given quantic or quantics; the invariants of the system of emanants will be functions of the derived functions of the given quantic or quantics, and they will be covariants of such quantic or quantics; and we thus pass from the invariants of a quantic or quantics to the covariants of a quantic or quantics of a higher order or orders.

72. It may be observed also, that in the case where a tantipartite invariant, when the several quantics are put equal to each other, does not become equal to zero, we may pass back from the invariant of the single quantic to the tantipartite invariant of the system; thus the lineo-linear invariant $ac'-2bb'+ca'$ of two quadrics leads to the quadrinvariant $ac-b^2$ of a single quantic; and *conversely*, from the quadrinvariant $ac-b^2$ of a single quadric, we obtain by an obvious process of derivation the expression $ac'-2bb'+ca'$ of the lineo-linear invariant of two quadrics. This is in fact included in the more general theory explained, No. 64.

73. Reverting now to binary quantics, two quantics of the same order, even or odd, have a lineo-linear invariant. Thus the two quadrics

$$(a, b, c \between x, y)^2, (a', b', c' \between x, y)^2$$

have (it has been seen) the lineo-linear invariant

$$ac'-2bb'+ca';$$

and in like manner the two cubics

$$(a, b, c, d \between x, y)^3, (a', b', c', d' \between x, y)^3$$

have the lineo-linear invariant

$$ad'-3bc'+3cb'-da',$$

which examples are sufficient to show the law.

74. The lineo-linear invariant of two quantics of the same odd order is a combinant, but this is not the case with the lineo-linear invariant of two quantics of the same even order. Thus the last-mentioned invariant is reduced to zero by each of the operations

$$a\partial_{a'}+b\partial_{b'}+c\partial_{c'}+d\partial_{d'}$$

and

$$a'\partial_a+b'\partial_b+c'\partial_c+d'\partial_d;$$

but the invariant

$$ac' \quad -2bb'+ca'$$

is by the operations

$$a\partial_{a'}+b\partial_{b'}+c\partial_{c'}$$

and

$$a'\partial_a+b'\partial_b+c'\partial_c$$

reduced respectively to

$$2(ac-b^2)$$

and

$$2(a'c'-b'^2).$$

75. For two quantics of the same odd order, when the quantics are put equal to each other, the lineo-linear invariant vanishes; but for two quantics of the same even order, when these are put equal to each other, we obtain the quadrinvariant of the single quantic. Thus the quadrinvariant of the quadric $(a, b, c \between x, y)^2$ is

$$ac-b^2;$$

and in like manner the quadrinvariant of the quartic $(a, b, c, d, e \between x, y)^4$ is

$$ae-4bd+3c^2.$$

76. When the two quantics are the first derived functions of the same quantic of any odd order, the lineo-linear invariant does not vanish, but it is not an invariant of the single quantic. Thus the lineo-linear invariant of

$$(a, b, c \between x, y)^2$$

and

$$(b, c, d \between x, y)^2$$

is

$$(ad-2bc+cb=)\,ad-bc,$$

which is not an invariant of the cubic

$$(a, b, c, d \between x, y)^3.$$

But for two quantics which are the first derived functions of the same quantic of any even order, the lineo-linear invariant is the quadrinvariant of the single quantic. Thus the lineo-linear invariant of

$$(a, b, c, d \between x, y)^3$$

and

$$(b, c, d, e \between x, y)^3$$

is

$$(ae-3bd+3c^2-db=)\,ae-4bd+3c^2,$$

which is the quadrinvariant of the quartic

$$(a, b, c, d, e \between x, y)^4.$$

77. I do not stop to consider the theory of the lineo-linear covariants of two quantics, but I derive the quadricovariants of a single quantic directly from the quadrinvariant. Imagine a quantic of any order even or odd. Its successive even emanants will be in regard to the facients of emanation quantics of an even order, and they will each of them have a quadrinvariant, which will be a quadricovariant of the given quantic. The emanants in question, beginning with the second emanant, are (in regard to the facients of the given quantic assumed to be of the order m) of the orders $m-2$, $m-4$, .. down to 1 or 0, according as m is odd or even, or writing successively $2p+1$ and $2p$ in the place of m, and taking the emanants in a reverse order, the emanants for a quantic of any odd order $2p+1$ are of the orders $1, 3, 5 \ldots 2p-1$, and for a quantic of any even order $2p$, they are of the orders $0, 2, 4 \ldots 2p-2$. The quadricovariants of a quantic of an odd order $2p+1$, are consequently of the orders $2, 6, 10 \ldots 4p-2$, and the quadricovariants of a quantic of an even order $2p$, are of the orders $0, 4, 8 \ldots 4p-4$. We might in each case carry the series one step further, and consider a quadricovariant of the order $4p+2$, or (as the case may be) $4p$, which arises from the 0th emanant of the given quantic; such quadricovariant is, however, only the square of the given quantic.

78. In the case of a quantic of an evenly even order (but in no other case) we have a quadricovariant of the same order with the quantic itself. We may in this case form the lineo-linear invariant of the quantic and the quadricovariant of the same order: such lineo-linear invariant is an invariant of the given quantic, and it is of the degree 3 in the

coefficients, that is, it is a cubinvariant. This agrees with the before-mentioned theorem for the number of cubinvariants.

79. In the case of the quartic $(a, b, c, d, e\between x, y)^4$, the cubinvariant is, by the preceding mode of generation, obtained in the form

$$e(ac-b^2)-4d\tfrac{3}{4}(ad-bc)+6c\tfrac{1}{8}(ae-4bd+3c^2)-4b\tfrac{3}{4}(be-cd)+a(ce-d^2),$$

which is in fact equal to

$$3(ace-ad^2-b^2e+2bcd-c^3);$$

and omitting the numerical factor 3, we have the cubinvariant of the quartic.

80. In the case of a quantic of any order even or odd, the quadrinvariants of the quadricovariants are quartinvariants of the quantic. But these quartinvariants are not all of them independent, and there is no obvious method grounded on the preceding mode of generation for obtaining the number of the independent (asyzygetic) quartinvariants, and thence the number of the irreducible quartinvariants of a quantic of a given order.

81. I take the opportunity of giving some additional developments in relation to the discriminant of a quantic

$$(a, b, \ldots b', a'\between x, y)^m.$$

To render the signification perfectly definite, it should be remarked that the discriminant contains the term $a^{m-1}a'^{m-1}$, and that the coefficient of this term may be taken to be $+1$. It was noticed in the introductory memoir, that, by JOACHIMSTHAL'S theorem, the discriminant, on putting $a=0$, becomes divisible by b^2, and that throwing out this factor it is to a numerical factor *près* the discriminant of the quantic of the order $(m-1)$ obtained by putting $a=0$ and throwing out the factor x; and it was also remarked, that this theorem, combined with the general property of invariants, afforded a convenient method for the calculation of the discriminant of a quantic when that of the order immediately preceding is known. Thus let it be proposed to find the discriminant of the cubic

$$(a, b, c, d\between x, y)^3.$$

Imagine the discriminant expanded in powers of the leading coefficient a in the form

$$\mathrm{A}a^2+\mathrm{B}a+\mathrm{C},$$

then this function *quà* invariant must be reduced to zero by the operation $3b\partial_a+2c\partial_b+d\partial_c$; or putting for shortness $\nabla=2c\partial_b+d\partial_c$, the operation is $\nabla+3b\partial_a$, and we have

$$\left.\begin{aligned} a^2\nabla\mathrm{A}+a\nabla\mathrm{B}\ &+\nabla\mathrm{C} \\ +a6b\mathrm{A}&+3b\mathrm{B}\end{aligned}\right\}=0,$$

and consequently

$$\mathrm{B}=-\frac{1}{3b}\nabla\mathrm{C},\ \mathrm{A}=-\frac{1}{6b}\nabla\mathrm{B},\ \nabla\mathrm{A}=0.$$

But C is equal to b^3 into the discriminant of $(3b, 3c, d\between x, y)^2$, that is, its value is $b^3(12bd-9c^2)$, or throwing out the factor 3, we may write

$$\mathrm{C}=4b^3d-3b^2c^2;$$

this gives

$$B=-\frac{1}{3b}(-6b^2cd+24b^2cd-12bc^3),$$

or reducing,

$$B=-6bcd+4c^3;$$

and thence

$$A=-\frac{1}{6b}(-6bd^2+12c^3d-12c^3d),$$

or reducing,

$$A=d^2,$$

which verifies the equation $\nabla A=0$, and the discriminant is, as we know,

$$a^2d^2-6abcd+4ac^3+4b^3d-3b^2c^2.$$

82. If we consider the quantic $(a, b..a'\between x, 1)^m$ as expressed in terms of the roots in the form $a(x-\alpha y)(x-\beta y)\ldots$, then the discriminant $(=a^{m-1}a'^{m-1}+\text{\&c. as above})$ is to a factor *près* equal to the product of the squares of the differences of the roots, and the factor may be determined as follows: viz. denoting by $\zeta(\alpha, \beta, \ldots)$ the product of the squares of the differences of the roots, we may write

$$a^{2m-2}\zeta(\alpha, \beta, ..)=N(a^{m-1}a'^{m-1}+\text{\&c.}),$$

where N is a number; and then considering the equation $x^m-1=0$, we have to determine N the equation

$$\zeta(\alpha, \beta, ..)=(-)^{m-1}N.$$

But in general

$$\zeta(\alpha, \beta..)=(-)^{\frac{1}{2}m(m-1)}(\alpha-\beta)(\alpha-\gamma)..(\beta-\alpha)(\beta-\gamma)\ldots$$

and if

$$\phi x=(x-\alpha)(x-\beta)..,$$

then

$$(\alpha-\beta)(\alpha-\gamma)..=\phi'\alpha, \text{ \&c.},$$

or

$$\zeta(\alpha, \beta, \ldots)=(-)^{\frac{1}{2}m(m-1)}\phi'\alpha\phi'\beta..;$$

here

$$\phi x=x^m-1,\ \phi'x=mx^{m-1},$$

and therefore

$$\phi'\alpha\phi'\beta..=m^m(\alpha\beta\gamma\ldots)^{m-1},$$

but

$$(-)^m\alpha\beta\gamma..=-1,$$

or

$$\alpha\beta\gamma..=(-)^{m-1}1,$$

and

$$\phi'\alpha\phi'\beta..=(-)^{(m-1)^2}m^m=(-)^{m-1}m^m;$$

whence

$$\zeta(\alpha, \beta\ldots)=(-)^{m-1+\frac{1}{2}m(m-1)}m^m=(-)^{m-1}N,$$

or

$$N=(-)^{\frac{1}{2}m(m-1)}m^m,$$

and consequently

$$a^{m-2}\zeta(\alpha, \beta, ..)=(-)^{\frac{1}{2}m(m-1)}m^m(a^{m-1}a'^{m-1}+\text{\&c.}),$$

or what is the same thing, the value of the discriminant $\square(=a^{m-1}a'^{m-1}+\&c.)$ is

$$(-)^{\frac{1}{2}m(m-1)}m^{-m}a^{m-2}\zeta(\alpha, \beta, \ldots).$$

It would have been allowable to define the discriminant so as that the leading term should be

$$(-)^{\frac{1}{2}m(m-1)}a^{m-1}a'^{m-1},$$

in which case the discriminant would have constantly the same sign as the product of the squared differences; but I have upon the whole thought it better to make the leading term of the discriminant always positive.

83. A quantic of an even order $2p$ has an invariant of peculiar simplicity, viz. the determinant the terms of which are the coefficients of the pth differential coefficients, or derived functions of the quantic with respect to the facients; such invariant may also be considered as a tantipartite invariant of the pth emanants. Thus the sextic

$$(a, b, c, d, e, f, g\between x, y)^6$$

has for one of its invariants, the determinant

$$\begin{vmatrix} a, & b, & c, & d \\ b, & c, & d, & e \\ c, & d, & e, & f \\ d, & e, & f, & g \end{vmatrix}$$

The invariant in question is termed by Professor SYLVESTER the *Catalecticant*.

84. Professor SYLVESTER also remarked, that we may from the catalecticant form a function containing an indeterminate quantity λ, such that the coefficients of the different powers of λ are invariants of the quantic; thus for the sextic, the function in question is

$$\begin{vmatrix} a & , & b & , & c & , & d-\lambda \\ b & , & c & , & d+\frac{1}{3}\lambda, & & e \\ c & , & d-\frac{1}{3}\lambda, & & e & , & f \\ d+\lambda, & & e & , & f & , & g \end{vmatrix}$$

where the law of formation is manifest; the terms in the sinister diagonal are modified by annexing to their numerical submultiples of λ with the signs $+$ and $-$ alternately, and in which the multipliers are the reciprocals of the binomial coefficients. The function so obtained is termed the *Lambdaic*.

85. If we consider a quantic of an odd order, and form the catalecticant of the penultimate emanant, we have the covariant termed the Canonisant. Thus in the case of the quintic

$$(a, b, c, d, e, f\between x, y)^5,$$

the canonisant is

$$\begin{vmatrix} ax+by, & bx+cy, & cx+dy \\ bx+cy, & cx+dy, & dx+ey \\ cx+dy, & dx+ey, & ex+fy \end{vmatrix}$$

which is equivalent to

$$\begin{vmatrix} y^3, & -y^2x, & yx^2, & -x^3 \\ a, & b, & c, & d \\ b, & c, & d, & e \\ c, & d, & e, & f \end{vmatrix}$$

and a like transformation exists with respect to the canonisant of a quantic of any odd order whatever. The canonisant and the lambdaic (which includes of course the catalecticant) form the basis of Professor SYLVESTER's theory of the *Canonical Forms* of quantics of an odd and an even order respectively.

86. There is another family of covariants which remains to be noticed. Consider any two quantics of the same order,

$$(a, b, ..\between x, y)^m,$$
$$(a', b', ..\between x, y)^m,$$

and join to these a quantic of the next inferior order,

$$(u, v, ..\between y, -x)^{m-1},$$

where the coefficients $(u, v, ..)$ are considered as indeterminate, and which may be spoken of as the adjoint quantic.

Take the odd lineo-linear covariants (viz. those which arise from the odd emanants) of the two quantics; the term arising from the $(2i+1)$th emanants is of the form

$$(\mathrm{A}, \mathrm{B}, ..\between x, y)^{2(m-1-2i)},$$

where $(\mathrm{A}, \mathrm{B}, ..)$ are lineo-linear functions of the coefficients of the two quantics.

Take also the quadricovariants of the adjoint quantic; the term arising from the $(2i-m)$th emanant is of the form

$$(\mathrm{U}, \mathrm{V}, ..\between x, y)^{2(m-1-2i)},$$

where $(\mathrm{U}, \mathrm{V}, ..)$ are quadric functions of the indeterminate coefficients $(u, v, ..)$. We may then form the quadrinvariant of the two quantics of the order $2(m-1-2i)$: this will be an invariant of the two quantics and the adjoint quantic, lineo-linear in the coefficients of the two quantics and of the degree 2 in regard to the coefficients $(u, v, ..)$ of the adjoint quantic; or treating the last-mentioned coefficients as facients, the result is a lineo-linear m-ary quadric of the form

$$(\mathfrak{A}, \mathfrak{B}, ..\between u, v, ..)^2,$$

viz. in this expression the coefficients $\mathfrak{A}, \mathfrak{B}, ..$ are lineo-linear functions of the coefficients of the two quantics. And giving to i the different admissible values, viz. from $i=0$ to $i=\frac{1}{2}m-1$ or $\frac{1}{2}(m-1)-1$, according as m is even or odd, the number of the functions obtained by the preceding process is $\frac{1}{2}m$ or $\frac{1}{2}(m-1)$, according as m is even or odd. The functions in question, the theory of which is altogether due to Professor SYLVESTER, are termed by him *Cobezoutiants*; we may therefore say that a cobezoutiant is an invariant of two quantics of the same order m, and of an adjoint quantic of the next preceding

order $m-1$, viz. treating the coefficients of the adjoint quantic as the facients of the cobezoutiant, the cobezoutiant is an m-ary quadric, the coefficients of which are lineo-linear functions of the coefficients of the two quantics, and the number of the cobezoutiants is $\frac{1}{2}m$ or $\frac{1}{2}(m-1)$, according as m is even or odd.

87. If the two quantics are the differential coefficients, or first derived functions (with respect to the facients) of a single quantic

$$(a, b, ..\between x, y)^m,$$

then we have what are termed the *Cobezoutoids* of the single quantic, viz. the cobezoutoid is an invariant of the single quantic of the order m, and of an adjoint quantic of the order $(m-2)$; and treating the coefficients of the adjoint quantic as facients, the cobezoutoid is an $(m-1)$ary quadric, the coefficients of which are quadric functions of the coefficients of the given quantic. The number of the cobezoutoids is $\frac{1}{2}(m-1)$ or $\frac{1}{2}(m-2)$, according as m is odd or even.

88. Consider any two quantics of the same order,

$$(a, ..\between x, y)^m,\ (a', ..\between x, y)^m,$$

and introducing the new facients (X, Y), form the quotient of determinants,

$$\begin{vmatrix} (a, ..\between x, y)^m, & (a', ..\between x, y)^m \\ (a, ..\between X, Y)^m, & (a', ..\between X, Y)^m \end{vmatrix} \div \begin{vmatrix} x, & y \\ X, & Y \end{vmatrix}$$

which is obviously an integral function of the order $(m-1)$ in each set of facients separately, and lineo-linear in the coefficients of the two quantics; for instance, if the two quantics are

$$(a, b, c, d \between x, y)^3,$$
$$(a', b', c', d' \between x, y)^3,$$

the quotient in question may be written

$$\left(\begin{vmatrix} 3(ab'-a'b), & 3(ac'-a'c) & , & ad'-a'd \\ 3(ac'-a'c), & ad'-a'd+9(bc'-b'c), & & 3(bd'-b'd) \\ ad'-a'd, & 3(bd'-b'd) & , & 3(cd'-c'd) \end{vmatrix} \between x, y \between X, Y)^2$$

The function so obtained may be termed the *Bezoutic Emanant* of the two quantics.

89. The notion of such function was in fact suggested to me by BEZOUT's abbreviated process of elimination, viz. the two quantics of the order m being put equal to zero, the process leads to $(m-1)$ equations each of the order $(m-1)$: these equations are nothing else than the equations obtained by equating to zero the coefficients of the different terms of the series $(X, Y)^{m-1}$ in the Bezoutic emanant, and the result of the elimination is consequently obtained by equating to zero the determinant formed with the matrix which enters into the expression of the Bezoutic emanant. In other words, this determinant is the Resultant of the two quantics. Thus the resultant of the last-mentioned two cubics is the determinant

$$\begin{vmatrix} 3(ab'-a'b), & 3(ac'-a'c), & ad'-a'd \\ 3(ac'-a'c), & ad'-a'd+9(bc'-b'c), & 3(bd'-b'd) \\ ad'-a'd, & 3(bd'-b'd), & 3(cd'-c'd) \end{vmatrix}$$

90. If the two quantics are the differential coefficients or first derived functions (with respect to the facients) of a single quantic of the order m, then we have in like manner the *Bezoutoidal Emanant* of the single quantic; this is a function of the order $m-2$ in each set of facients, and the coefficients whereof are quadric functions of the coefficients of the single quantic. Thus the Bezoutoidal emanant of the quartic

$$(a, b, c, d, e \between x, y)^4$$

is

$$\left(\begin{vmatrix} 3(ac-b^2), & 3(ad-bc), & ae-bd \\ 3(ad-bc), & ae+8bd-9c^2, & 3(be-cd) \\ ae-bd, & 3(be-cd), & 3(ce-d^2) \end{vmatrix} \between x, y \right)^2 (\between X, Y)^2$$

and of course the determinant formed with the matrix which enters into the expression of the Bezoutoidal Emanant, is the discriminant of the single quantic.

91. Professor SYLVESTER forms with the matrix of the Bezoutic emanant and a set of m facients $(u, v, \ldots)$ an m-ary quadric function, which he terms the *Bezoutiant*. Thus the Bezoutiant of the before-mentioned two cubics is

$$\left(\begin{vmatrix} 3(ab'-a'b), & 3(ac'-a'c), & ad'-a'd \\ 3(ac'-a'c), & ad'-a'd+9(bc'-b'c), & 3(bd'-b'd) \\ ad'-a'd, & 3bd'-b'd, & 3(cd'-c'd) \end{vmatrix} \between u, v, w \right)^2;$$

and in like manner with the Bezoutoidal emanant of the single quantic of the order m and a set of $(m-1)$ new facients $(u, v, \ldots)$, an $(m-1)$ary quadric function, which he terms the *Bezoutoid*. Thus the Bezoutoid of the before-mentioned quartic is

$$\left(\begin{vmatrix} 3(ac-b^2), & 3(ad-bc), & ae-bd \\ 3(ad-bc), & ae+8bd-9c^2, & 3(be-cd) \\ ae-bd, & 3(be-cd), & 3(ce-d^2) \end{vmatrix} \between u, v, w \right)^2;$$

And to him is due the important theorem, that the Bezoutiant is an invariant of the two quantics of the order m and of the adjoint quantic $(u, v, \ldots \between y, -x)^{m-1}$, being in fact a linear function with mere numerical coefficients, of the invariants called Cobezoutiants, and in like manner that the Bezoutoid is an invariant of the single quantic of the order m and of the adjoint quantic $(u, v, \ldots \between y, -x)^{m-2}$, being a linear function with mere numerical coefficients of the invariants called Cobezoutoids.

The modes of generation of a covariant are infinite in number, and it is to be anticipated that, as new theories arise, there will be frequent occasion to consider new processes of derivation, and to single out and to define and give names to new covariants. But I have now, I think, established the greater part by far of the definitions which are for the present necessary.

XXIII. *A Fifth Memoir upon Quantics.* By Arthur Cayley, *Esq.*, *F.R.S.*

Received February 11,—Read March 18, 1858.

The present memoir was originally intended to contain a development of the theories of the covariants of certain binary quantics, viz. the quadric, the cubic, and the quartic; but as regards the theories of the cubic and the quartic, it was found necessary to consider the case of two or more quadrics, and I have therefore comprised such systems of two or more quadrics, and the resulting theories of the harmonic relation and of involution, in the subject of the memoir; and although the theory of homography or of the anharmonic relation belongs rather to the subject of bipartite binary quadrics, yet from its connexion with the theories just referred to, it is also considered in the memoir. The paragraphs are numbered continuously with those of my former memoirs on the subject: Nos. 92 to 95 relate to a single quadric; Nos. 96 to 114 to two or more quadrics, and the theories above referred to; Nos. 115 to 127 to the cubic, and Nos. 128 to 145 to the quartic. The several quantics are considered as expressed not only in terms of the coefficients, but also in terms of the roots,—and I consider the question of the determination of their linear factors,—a question, in effect, identical with that of the solution of a quadric, cubic, or biquadratic equation. The expression for the linear factor of a quadric is deduced from a well-known formula; those for the linear factors of a cubic and a quartic were first given in my "Note sur les Covariants d'une fonction quadratique, cubique ou biquadratique à deux indéterminées," Crelle, vol. L. pp. 285 to 287, 1855. It is remarkable that they are in one point of view more simple than the expression for the linear factor of a quadric.

92. In the case of a quadric the expressions considered are

$$(a, b, c\between x, y)^2, \qquad (1)$$

$$ac-b^2 \quad , \qquad (2)$$

where (1) is the quadric, and (2) is the discriminant, which is also the quadrinvariant, catalecticant, and Hessian.

And where it is convenient to do so, I write

$$(1) = \mathrm{U},$$

$$(2) = \square.$$

93. We have

$$(\partial_c, -\partial_b, \partial_a\between x, y)^2\square = \mathrm{U},$$

which expresses that the evectant of the discriminant is equal to the quadric;

$$(a, b, c\between\partial_y, -\partial_x)^2\mathrm{U}=4\square,$$

which expresses that the provectant of the quadric is equal to the discriminant;

$$(a, b, c\between bx+cy, -ax-by)^2=\square\mathrm{U},$$

which expresses that a transmutant of the quadric is equal to the product of the quadric and the discriminant.

94. When the quadric is expressed in terms of the roots, we have

$$a^{-1}\mathrm{U}=(x-\alpha y)(x-\beta y),$$
$$a^{-2}\square=-\tfrac{1}{4}(\alpha-\beta)^2;$$

and in the case of a pair of equal roots,

$$a^{-1}\mathrm{U}=(x-\alpha y)^2,$$
$$\square\quad=0.$$

95. The problem of the solution of a quadratic equation is that of finding a linear factor of the quadric. To obtain such linear factor in a symmetrical form, it is necessary to introduce arbitrary quantities which do not really enter into the solution, and the form obtained is thus in some sort more complicated than in the like problem for a cubic or a quartic. The solution depends on the linear transformation of the quadric, viz. if we write

$$(a, b, c\between\lambda x+\mu y, \nu x+\varrho y)^2=(a', b', c'\between x, y)^2,$$

so that

$$a'=(a, b, c\between\lambda, \nu)^2,$$
$$b'=(a, b, c\between\lambda, \nu\between\mu, \varrho),$$
$$c'=(a, b, c\between\mu, \varrho)^2,$$

then

$$a'c'-b'^2=(ac-b^2)(\lambda\varrho-\mu\nu)^2,$$

an equation which in a different notation is

$$(a, b, c\between x, y)^2.(a, b, c\between\mathrm{X}, \mathrm{Y})^2-\overline{(a, b, c\between x, y\between\mathrm{X}, \mathrm{Y})}^2=\square(\mathrm{Y}x-\mathrm{X}y)^2,$$

in which form it is a theorem relating to the quadric and its first and second emanants. The equation shows that

$$(a, b, c\between x, y\between\mathrm{X}, \mathrm{Y})+\sqrt{-\square}(\mathrm{Y}x-\mathrm{X}y),$$

where (X, Y) are treated as supernumerary arbitrary constants, is a linear factor of $(a, b, c\between x, y)^2$, and this is the required solution.

96. In the case of two quadrics, the expressions considered are

$$(a, b, c\between x, y)^2, \qquad (1)$$
$$(a', b', c'\between x, y)^2, \qquad (2)$$
$$ac-b^2 \quad , \qquad (3)$$
$$ac'-2bb'+ca' \quad , \qquad (4)$$
$$a'c'-b'^2 \quad , \qquad (5)$$

(6)

$$(ab'-a'b,\ ac'-a'c,\ bc'-b'c \quad \between(x, y)^2, \tag{7}$$

$$(\lambda a+\mu a',\ \lambda b+\mu b',\ \lambda c+\mu c' \quad \between(x, y)^2, \tag{8}$$

$$(ac-b^2\ ,\ ac'-2bb'+ca',\ a'c'-b'^2 \between(\lambda, \mu)^2, \tag{9}$$

(1) and (2) are the quadrics, (3) and (5) are the discriminants, and (4) is the lineo-linear invariant, or connective of the discriminants; (6) is the resultant of the two quadrics, (7) is the Jacobian, (8) is an intermediate, and (9) is the discriminant of the intermediate. And where it is convenient to do so, I write

$$\begin{aligned}
(1) &= \mathrm{U},\\
(2) &= \mathrm{U}',\\
(3) &= \square,\\
(4) &= \mathrm{Q},\\
(5) &= \square',\\
(6) &= \mathrm{R},\\
(7) &= \mathrm{H},\\
(8) &= \mathrm{W},\\
(9) &= \Theta.
\end{aligned}$$

97. The Jacobian (7) may also be written in the form

$$\begin{vmatrix} y^2, & -yx, & x^2 \\ a\ , & b\ , & c \\ a', & b'\ , & c' \end{vmatrix},$$

The Resultant (6) may be written in the form

$$\begin{vmatrix} & a, & 2b\ , & c & \\ a\ , & 2b\ , & c\ , & & \\ & a', & 2b', & c' & \\ a', & 2b', & c', & & \end{vmatrix},$$

and also, taken negatively, in the form

$$4(ab'-a'b)(bc'-b'c)-(ac'-a'c)^2,$$

which is the discriminant of the Jacobian; and in the form

$$4(ac-b^2)(a'c'-b'^2)-(ac'-2bb'+ca')^2,$$

which is the discriminant of the Intermediate.

98. We have the following relations:—

$$\begin{aligned}(a, b, c\between b'x+c'y, -a'x-b'y)^2= \\ -(a'c'-b'^2) \quad & (a, b, c\between x, y)^2 \\ +(ac'-2bb'+ca') \quad & (a', b', c'\between x, y)^2, \\ (a', b', c'\between bx+cy, -ax-by)^2= \\ +(ac'-2bb'+ca') \quad & (a, b, c\between x, y)^2 \\ -(ac-b^2) \quad & (a', b', c'\between x, y)^2,\end{aligned}$$

and, moreover,

$$\begin{aligned}(ac-b^2, ac'-2bb'+ca', a'c'-b'^2\between U', -U)^2 \\ =-\{(ab'-a'b, ac'-a'c, bc'-b'c\between x, y)^2\}^2,\end{aligned}$$

an equation, the interpretation of which will be considered in the sequel.

99. The most important relations which may exist between the two quadrics are—

First, when the connective vanishes, or

$$ac'-2bb'+ca'=0,$$

in which case the two quadrics are said to be *harmonically* related: the nature of this relation will be further considered.

Secondly, when $R=0$, the two quadrics have in this case a common root, which is given by any of the equations,

$$\begin{aligned}x^2:2xy:y^2=\partial_a R \quad &:\partial_b R \quad :\partial_c R \\ =\partial_{a'} R \quad &:\partial_{b'} R \quad :\partial_{c'} R \\ =bc'-b'c:ca'-c'a:ab'-a'b.\end{aligned}$$

The last set of values express that the Jacobian is a perfect square, and that the two roots are each equal to the common root of the two quadrics.

The preceding values of the ratios $x^2:2xy:y^2$ are consistent with each other in virtue of the assumed relation $R=0$, hence in general the functions

$$4\partial_a R.\partial_c R-(\partial_b R)^2,\ \partial_a R.\partial_{b'} R-\partial_b R.\partial_{a'} R, \text{ \&c.}$$

all of them contain the Resultant R as a factor.

It is easy to see that the Jacobian is harmonically related to each of the quadrics; in fact we have identically

$$a(bc'-b'c)+b(ca'-c'a)+c(ab'-a'b)=0,$$
$$a'(bc'-b'c)+b'(ca'-c'a)+c'(ab'-a'b)=0,$$

which contain the theorem in question.

100. When the quadrics are expressed in terms of the roots, we have

$$\begin{aligned}
a^{-1}\mathrm{U} &= (x-\alpha y)(x-\beta y),\\
a'^{-1}\mathrm{U}' &= (x-\alpha' y)(x-\beta' y),\\
4a^{-2}\square &= -(\alpha-\beta)^2,\\
2(aa')^{-1}\mathrm{Q} &= 2\alpha\beta+2\alpha'\beta'-(\alpha+\beta)(\alpha'+\beta'),\\
4a'^{-2}\square' &= -(\alpha'-\beta')^2,\\
(aa')^{-2}\mathrm{R} &= (\alpha-\alpha')(\alpha-\beta')(\beta-\alpha')(\beta-\beta'),\\
(aa')^{-1}\mathrm{H} &= \begin{vmatrix} y^2, & 2yx, & x^2 \\ 1, & \alpha+\beta, & \alpha\beta \\ 1, & \alpha'+\beta', & \alpha'\beta' \end{vmatrix},
\end{aligned}$$

101. The comparison of the last-mentioned value of R with the expression in terms of the roots obtained from the equation

$$-\mathrm{R}=4\square\square'-\mathrm{Q}^2,$$

gives the identical equation

$$(\alpha-\beta)^2(\alpha'-\beta')^2-\{2\alpha\beta+2\alpha'\beta'-(\alpha+\beta)(\alpha'+\beta')\}^2=-4(\alpha-\alpha')(\alpha-\beta')(\beta-\alpha')(\beta-\beta'),$$

which may be easily verified.

102. We have identically

$$\begin{aligned}
&2\alpha\beta+2\alpha'\beta'-(\alpha+\beta)(\alpha'+\beta')\\
&\quad=2(\alpha-\alpha')(\alpha-\beta')-(\alpha-\beta)(2\alpha-\alpha'-\beta')\\
&\quad=2(\beta-\alpha')(\beta-\beta')-(\beta-\alpha)(2\beta-\alpha'-\beta')\\
&\quad=2(\alpha'-\alpha)(\alpha'-\beta)-(\alpha'-\beta')(2\alpha'-\alpha-\beta)\\
&\quad=2(\beta'-\alpha)(\beta'-\beta)-(\beta'-\alpha')(2\beta'-\alpha-\beta);
\end{aligned}$$

and the equation $\mathrm{Q}=ad'-2bb'+ca'=0$ may consequently be written in the several forms

$$\frac{2}{\alpha-\beta}=\frac{1}{\alpha-\alpha'}+\frac{1}{\alpha-\beta'},$$

$$\frac{2}{\beta-\alpha}=\frac{1}{\beta-\alpha'}+\frac{1}{\beta'-\beta},$$

$$\frac{2}{\alpha'-\beta'}=\frac{1}{\alpha'-\alpha}+\frac{1}{\alpha'-\beta},$$

$$\frac{2}{\beta'-\alpha'}=\frac{1}{\beta'-\alpha}+\frac{1}{\beta'-\beta},$$

so that the roots (α, β), (α', β') are harmonically related to each other, and hence the notion of the harmonic relation of the two quadrics.

103. In the case where the two quadrics have a common root $\alpha=\alpha'$,

$$\begin{aligned}
a^{-1}\mathrm{U} &= (x-\alpha y)(x-\beta y),\\
a'^{-1}\mathrm{U}' &= (x-\alpha y)(x-\beta' y),
\end{aligned}$$

$$\begin{aligned}
4a^{-2}\square &= -(\alpha-\beta)^2,\\
2(aa')^{-1}\mathrm{Q} &= (\alpha-\beta)(\alpha-\beta'),\\
4a'^{-2}\square' &= (\alpha-\beta')^2,\\
\mathrm{R} &= 0\\
(aa')^{-1}\mathrm{H} &= (\beta'-\beta)(x-\alpha y)^2.
\end{aligned}$$

104. In the case of three quadrics, of the expressions which are or might be considered, it will be sufficient to mention

$$\begin{array}{ll}
(a\,,\ b\,,\ c\,\between x,\ y)^2, & (1)\\
(a',\ b',\ c'\between x,\ y)^2, & (2)\\
(a'',\ b'',\ c''\between x,\ y)^2, & (3)\\
\begin{vmatrix} a\,, & b\,, & c \\ a', & b', & c' \\ a'', & b'', & c'' \end{vmatrix}, & (4)
\end{array}$$

where (1), (2), (3) are the quadrics themselves, and (4) is an invariant, linear in the coefficients of each quadric. And where it is convenient to do so, I write

$$\begin{aligned}
(1) &= \mathrm{U},\\
(2) &= \mathrm{U}',\\
(3) &= \mathrm{U}'',\\
(4) &= \Omega.
\end{aligned}$$

105. The equation $\Omega=0$ is, it is clear, the condition to be satisfied by the coefficients of the three quadrics, in order that there may be a syzygetic relation $\lambda\mathrm{U}+\mu\mathrm{U}'+\nu\mathrm{U}''=0$, or what is the same thing, in order that each quadric may be an intermediate of the other two quadrics; or again, in order that the three quadrics may be *in Involution*. Expressed in terms of the roots, the relation is

$$\begin{vmatrix} 1, & \alpha+\beta\,, & \alpha\beta \\ 1, & \alpha'+\beta', & \alpha'\beta' \\ 1, & \alpha''+\beta'', & \alpha''\beta'' \end{vmatrix}=0;$$

and when this equation is satisfied, the three pairs, or as it is usually expressed, the six quantities α, β; α', β'; α'', β'', are said to be in involution, or to form an involution. And the two perfectly arbitrary pairs α, β; α', β' considered as belonging to such a system, may be spoken of as an involution. If the two terms of a pair are equal, *e. g.* if $\alpha''=\beta''=\theta$, then the relation is

$$\begin{vmatrix} 1, & 2\theta\,, & \theta^2 \\ 1, & \alpha+\beta, & \alpha\beta \\ 1, & \alpha'+\beta', & \alpha'\beta' \end{vmatrix}=0;$$

and such a system is sometimes spoken of as an involution of five terms. Considering

the pairs (α, β), (α', β') as given, there are of course two values of θ which satisfy the preceding equation; and calling these $\theta_{\prime}$ and $\theta_{\prime\prime}$, then $\theta_{\prime}$ and $\theta_{\prime\prime}$ are said to be the sibiconjugates of the involution α, β; α', β'. It is easy to see that $\theta_{\prime}, \theta_{\prime\prime}$ are the roots of the equation $H=0$, where H is the Jacobian of the two quadrics U and U′ whose roots are (α, β), (α', β'). In fact, the quadric whose roots are $\theta_{\prime}, \theta_{\prime\prime}$ is

$$\begin{vmatrix} y^2, & 2yx, & x^2 \\ 1, & \alpha+\beta, & \alpha\beta \\ 1, & \alpha'+\beta', & \alpha'\beta' \end{vmatrix}$$

which has been shown to be the Jacobian in question. But this may be made clearer as follows:—If we imagine that λ, μ are determined in such manner that the intermediate $\lambda U+\mu U'$ may be a perfect square, then we shall have $\lambda U+\mu U'=a''(x-\theta y)^2$, where θ denotes one or other of the sibiconjugates $\theta_{\prime}, \theta_{\prime\prime}$ of the involution. But the condition in order that $\lambda U+\mu U'$ may be a square is

$$(ac-b^2, ac'-2bb'+ca', a'c'-b'^2)(\lambda, \mu)^2;$$

and observing that the equation $\lambda:\mu=U':-U$ implies $\lambda U+\mu U'=0=a''(x-\theta y)^2$, it is obvious that the function

$$(ac-b^2, ac'-2bb'+ca', a'c'-b'^2)(U', -U)^2$$

must be to a factor *près* equal to $(x-\theta y)^2(x-\theta_{\prime\prime}y)^2$. But we have identically

$$(ac-b^2, ac'-2bb'+ca', a'c'-b'^2)(U', -U)^2=-\{(ab'-a'b, ac'-a'c, bc'-b'c)(x, y)^2\}^2,$$

and we thus see that $(x-\theta y)$, $(x-\theta_{\prime\prime}y)$ are the factors of the Jacobian.

106. It has been already remarked that the Jacobian is harmonically related to each of the quadrics U, U′; hence we see that the sibiconjugates $\theta_{\prime}, \theta_{\prime\prime}$ of the involution α, β, α', β' are a pair harmonically related to the pair α, β, and also harmonically related to the pair α', β', and this properly might be taken as the definition for the sibiconjugates $\theta_{\prime}, \theta_{\prime\prime}$ of an involution of four terms. And moreover, α, β; α', β' being given, and $\theta_{\prime}, \theta_{\prime\prime}$ being determined as the sibiconjugates of the involution, if α'', β'' be a pair harmonically related to $\theta_{\prime}, \theta_{\prime\prime}$, then the three pairs α, β; α', β'; α'', β'' will form an involution; or what is the same thing, any three pairs α, β; α', β'; α'', β'', each of them harmonically related to a pair $\theta_{\prime}, \theta_{\prime\prime}$, will be an involution, and $\theta_{\prime}, \theta_{\prime\prime}$ will be the sibiconjugates of the involution.

107. In particular, if α, β be harmonically related to $\theta_{\prime}, \theta_{\prime\prime}$, then it is easy to see that $\theta_{\prime}, \theta_{\prime}$ may be considered as harmonically related to $\theta_{\prime}, \theta_{\prime\prime}$, and in like manner $\theta_{\prime\prime}, \theta_{\prime\prime}$ will be harmonically related to $\theta_{\prime}, \theta_{\prime\prime}$; that is, the pairs $\theta_{\prime}, \theta_{\prime}$; $\theta_{\prime\prime}, \theta_{\prime\prime}$ and α, β will form an involution. This comes to saying that the equation

$$\begin{vmatrix} 1, & 2\theta_{\prime}, & \theta_{\prime}^2 \\ 1, & 2\theta_{\prime\prime}, & \theta_{\prime\prime}^2 \\ 1, & \alpha+\beta, & \alpha\beta \end{vmatrix}=0$$

is equivalent to the harmonic relation of the pairs α, β; θ_i, θ_{ii}; and in fact the determinant is

$$(\theta_i-\theta_{ii})\big(2\alpha\beta+2\theta_i\theta_{ii}-(\alpha+\beta)(\theta_i+\theta_{ii})\big),$$

which proves the theorem in question.

108. Before proceeding further, it is proper to consider the equation

$$\begin{vmatrix} 1, & \alpha, & \alpha', & \alpha\alpha' \\ 1, & \beta, & \beta', & \beta\beta' \\ 1, & \gamma, & \gamma', & \gamma\gamma' \\ 1, & \delta, & \delta', & \delta\delta' \end{vmatrix}=0,$$

which expresses that the sets $(\alpha, \beta, \gamma, \delta)$ and $(\alpha', \beta', \gamma', \delta')$ are homographic; for although the homographic equation may be considered as belonging to the theory of the bipartite quadric $(x-\alpha y)(x-\alpha' y)$, yet the theory of involution cannot be completely discussed except in connexion with that of homography. If we write

$$A=(\beta-\gamma)(\alpha-\delta),\quad B=(\gamma-\alpha)(\beta-\delta),\quad C=(\alpha-\beta)(\gamma-\delta),$$
$$A'=(\beta'-\gamma')(\alpha'-\delta'),\quad B'=(\gamma'-\alpha')(\beta'-\delta'),\quad C'=(\alpha'-\beta')(\gamma'-\delta'),$$

then we have

$$A+B+C=0,$$
$$A'+B'+C'=0,$$

and thence

$$BC'-B'C=CA'-C'A=AB'-A'B;$$

and either of these expressions is in fact equal to the last-mentioned determinant, as may be easily verified. Hence, when the determinant vanishes, we have

$$A:B:C=A':B':C'.$$

Any one of the three ratios $A:B:C$, for instance the ratio $B:C=$

$$\frac{(\gamma-\alpha)(\beta-\delta)}{(\alpha-\beta)(\gamma-\delta)},$$

is said to be the anharmonic ratio of the set $(\alpha, \beta, \gamma, \delta)$, and consequently the two sets $(\alpha, \beta, \gamma, \delta)$ and $(\alpha', \beta', \gamma', \delta')$ will be homographically related when the anharmonic ratios (that is, the corresponding anharmonic ratios) of the two sets are equal.

If any one of the anharmonic ratios be equal to unity, then the four terms of the set taken in a proper manner in pairs, will be harmonics; thus the equation $\frac{B}{C}=1$ gives

$$\frac{(\gamma-\alpha)(\beta-\delta)}{(\alpha-\beta)(\gamma-\delta)}=1,$$

which is reducible to

$$2\alpha\delta+2\beta\gamma-(\alpha+\delta)(\beta+\gamma)=0,$$

which expresses that the pairs α, δ and β, γ are harmonics.

109. Now returning to the theory of involution (and for greater convenience taking α, α' &c. instead of α, β &c. to represent the terms of the same pair), the pairs α, α'; β, β';

γ, γ'; δ, δ' &c. will be in involution if each of the determinants formed with any three lines of the matrix

$$\begin{array}{llll} 1, & \alpha+\alpha', & \alpha\alpha', \\ 1, & \beta+\beta', & \beta\beta', \\ 1, & \gamma+\gamma', & \gamma\gamma', \\ 1, & \delta+\delta', & \delta\delta', \\ \&c. & & \end{array}$$

vanishes: but this being so, the determinant

$$\begin{vmatrix} 1, & \alpha, & \alpha', & \alpha\alpha' \\ 1, & \beta, & \beta', & \beta\beta' \\ 1, & \gamma, & \gamma', & \gamma\gamma' \\ 1, & \delta, & \delta', & \delta\delta' \end{vmatrix}$$

which is equal to

$$\begin{vmatrix} \alpha, & 1, & \alpha+\alpha', & \alpha\alpha' \\ \beta, & 1, & \beta+\beta', & \beta\beta' \\ \gamma, & 1, & \gamma+\gamma', & \gamma\gamma' \\ \delta, & 1, & \delta+\delta', & \delta\delta' \end{vmatrix}$$

will vanish, or the two sets $(\alpha, \beta, \gamma, \delta)$ and $(\alpha', \beta', \gamma', \delta')$ will be homographic; that is, if any number of pairs are in involution, then, considering four pairs and selecting in any manner a term out of each pair, these four terms and the other terms of the same four pairs form respectively two sets, the two sets so obtained will be homographic.

110. In particular, if we have only three pairs α, α'; β, β'; γ, γ', then the sets $\alpha, \beta, \gamma, \alpha'$ and $\alpha', \beta', \gamma', \alpha$ will be homographic; in fact, the condition of homography is

$$\begin{vmatrix} 1, & \alpha, & \alpha', & \alpha\alpha' \\ 1, & \beta, & \beta', & \beta\beta' \\ 1, & \gamma, & \gamma', & \gamma\gamma' \\ 1, & \alpha', & \alpha, & \alpha\alpha' \end{vmatrix} = 0,$$

which may be written

$$\begin{vmatrix} \alpha, & 1, & \alpha+\alpha', & \alpha\alpha' \\ \beta, & 1, & \beta+\beta', & \beta\beta' \\ \gamma, & 1, & \gamma+\gamma', & \gamma\gamma' \\ \alpha', & 1, & \alpha+\alpha', & \alpha\alpha' \end{vmatrix} = 0,$$

or what is the same thing,

$$\begin{vmatrix} \alpha & , & 1, & \alpha+\alpha', & \alpha\alpha' \\ \beta & , & 1, & \beta+\beta', & \beta\beta' \\ \gamma & , & 1, & \gamma+\gamma', & \gamma\gamma' \\ \alpha'-\alpha, & & 0, & 0 & , 0 \end{vmatrix} = 0,$$

so that the first-mentioned relation is equivalent to

$$(\alpha'-\alpha)\begin{vmatrix} 1, & \alpha+\alpha', & \alpha\alpha' \\ 1, & \beta+\beta', & \beta\beta' \\ 1, & \gamma+\gamma', & \gamma\gamma' \end{vmatrix}=0,$$

and the two sets give rise to an involution. The condition of homography as expressed by the equality of the anharmonic ratios may be written

$$\frac{\alpha-\beta.\gamma-\alpha'}{\alpha-\gamma.\alpha'-\beta}=\frac{\alpha'-\beta'.\gamma'-\alpha}{\alpha'-\gamma'.\alpha-\beta'};$$

or multiplying out,

$$(\alpha-\beta)(\alpha-\beta')(\alpha'-\gamma)(\alpha'-\gamma')-(\alpha'-\beta)(\alpha'-\beta')(\alpha-\gamma)(\alpha'-\gamma')=0,$$

which is a form for the equation of involution of the three pairs. But this and the other transformations of the equation of involution is best obtained by a different method, as will be presently seen.

111. Imagine now any number of pairs α, α'; β, β'; γ, γ'; δ, δ', &c. in involution, and let x, y, z, w be the fourth harmonics of the same quantity λ with respect to the pairs α, α'; β, β'; γ, γ' and δ, δ' respectively; then the anharmonic ratios of the set (x, y, z, w) will be independent of λ, or what is the same thing, if x', y', z', w' are the fourth harmonics of any other quantity λ' with respect to the same four pairs, the sets (x, y, z, w) and (x', y', z', w') will be homographic, or we shall have

$$\begin{vmatrix} 1, & x, & x', & xx' \\ 1, & y, & y', & yy' \\ 1, & z, & z', & zz' \\ 1, & w, & w', & ww' \end{vmatrix}=0.$$

It will be sufficient to show this in the case where λ is anything whatever, but λ' has a determinate value, say $\lambda'=\infty$; and since if all the terms α, α', &c. are diminished by the same quantity λ the relations of involution and homography will not be affected, we may without loss of generality assume $\lambda=0$, but in this case

$$x=\frac{2\alpha\alpha'}{\alpha+\alpha'},\ x'=\tfrac{1}{2}(\alpha+\alpha'),$$

and the equation to be proved is

$$\begin{vmatrix} 1, & \frac{\alpha\alpha'}{\alpha+\alpha'}, & \alpha+\alpha', & \alpha\alpha', \\ 1, & \frac{\beta\beta'}{\beta+\beta'}, & \beta+\beta', & \beta\beta', \\ 1, & \frac{\gamma\gamma'}{\gamma+\gamma'}, & \gamma+\gamma', & \gamma\gamma', \\ 1, & \frac{\delta\delta'}{\delta+\delta'}, & \delta+\delta', & \delta\delta', \end{vmatrix}=0,$$

which is obviously a consequence of the equations which express the involution of the four pairs.

A set homographic with x, y, z, w, which are the fourth harmonics of any quantity whatever λ with respect to the pairs in involution, α, α'; β, β'; γ, γ'; δ, δ', is said to be homographic with the four pairs, and we have thus the notion of a set of single quantities homographic with a set of pairs in involution. This very important theory is due to M. CHASLES.

112. Let r; s; t, be the anharmonic ratios of a set $\alpha, \beta, \gamma, \delta$, and let $r_{,}$; $s_{,}$; $t_{,}$ be the anharmonic ratios (corresponding or not corresponding) of a set $\alpha_{,}, \beta_{,}, \gamma_{,}, \delta_{,}$. And suppose that r'; s'; t'; $r'_{,}$; $s'_{,}$; $t'_{,}$; r''; s''; t''; $r''_{,}$; $s''_{,}$; $t''_{,}$; r'''; s'''; t'''; $r'''_{,}$; $s'''_{,}$; $t'''_{,}$, are the analogous quantities for three other pairs of sets; then an equation such as

$$\begin{vmatrix} 1, & \frac{r}{s}, & \frac{r_{,}}{s_{,}}, & \frac{rr_{,}}{ss_{,}} \\ \vdots & & & \end{vmatrix} = 0,$$

or as it is more conveniently written,

$$\begin{vmatrix} ss_{,}, & rs_{,}, & r_{,}s, & rr_{,} \\ s's'_{,}, & r's'_{,}, & r'_{,}s', & r'r'_{,} \\ s''s''_{,}, & r''s''_{,}, & r''_{,}s'', & r''r''_{,} \\ s'''s'''_{,}, & r'''s'''_{,}, & r'''_{,}s''', & r'''r'''_{,} \end{vmatrix} = 0$$

is a relation independent of the particular ratios $r:s$ which have been chosen for the anharmonic ratios of the sets; this is easily shown by means of the equations

$$r+s+t=0,\ r_{,}+s_{,}+t_{,}=0,$$

which connect the anharmonic ratios. The equation in fact expresses a certain relation between four sets $(\alpha, \beta, \gamma, \delta)$ and four other sets $(\alpha_{,}, \beta_{,}, \gamma_{,}, \delta_{,})$; a relation which may be termed the relation of the homography of the anharmonic ratios of four and four sets: the notion of this relation is also due to M. CHASLES.

113. The general relation

$$\begin{vmatrix} 1, & \alpha+\beta, & \alpha\beta \\ 1, & \alpha'+\beta', & \alpha'\beta' \\ 1, & \alpha''+\beta'', & \alpha''\beta'' \end{vmatrix} = 0$$

may be exhibited in a great variety of forms. In fact, if the determinant is denoted by Υ, then multiplying by this determinant the two sides of the identical equation

$$\begin{vmatrix} u^2, & -u, & 1 \\ v^2, & -v, & 1 \\ w^2, & -w, & 1 \end{vmatrix} = (u-v)(v-w)(w-u),$$

we obtain

$$\Upsilon(u-v)(v-w)(w-u) = \begin{vmatrix} (u-\alpha)(u-\beta), & (v-\alpha)(v-\beta), & (w-\alpha)(w-\beta) \\ (u-\alpha')(u-\beta'), & (v-\alpha')(v-\beta'), & (w-\alpha')(w-\beta') \\ (u-\alpha'')(u-\beta''), & (v-\alpha'')(v-\beta''), & (w-\alpha'')(w-\beta'') \end{vmatrix}$$

If, for example, $u=\alpha$, $v=\beta$, then we have

$$\Upsilon(\alpha-\beta)=-(\alpha-\alpha')(\alpha-\beta')(\beta-\alpha'')(\beta-\beta'')+(\beta-\alpha')(\beta-\beta')(\alpha-\alpha'')(\alpha-\beta'').$$

And again, if $u=\alpha$, $v=\alpha'$, $w=\alpha''$, then we have

$$\Upsilon \quad =-(\alpha-\beta'')(\alpha'-\beta)(\alpha''-\beta')+(\alpha-\beta')(\alpha'-\beta'')(\alpha''-\beta).$$

Or putting $\Upsilon=0$, the first equation gives

$$\frac{(\alpha-\alpha')(\beta-\alpha'')}{(\alpha-\alpha'')(\alpha'-\beta)}=\frac{(\alpha-\beta'')(\beta-\beta')}{(\alpha-\beta')(\beta''-\beta)};$$

and the second equation gives

$$(\alpha-\beta'')(\alpha'-\beta)(\alpha''-\beta')=(\alpha-\beta')(\alpha'-\beta'')(\alpha''-\beta),$$

which are both of them well-known forms.

114. A corresponding transformation applies to the equation

$$\begin{vmatrix} 1, & \alpha, & \alpha', & \alpha\alpha' \\ 1, & \beta, & \beta', & \beta\beta' \\ 1, & \gamma, & \gamma', & \gamma\gamma' \\ 1, & \delta, & \delta', & \delta\delta' \end{vmatrix}=0,$$

which expresses the homography of two pairs. In fact, calling the determinant Ψ and representing by V the similar determinant

$$\begin{vmatrix} ss', & -s', & -s, & 1 \\ tt', & -t', & -t, & 1 \\ uu', & -u', & -u, & 1 \\ vv', & -v', & -v, & 1 \end{vmatrix}$$

which, equated to zero, would express the homography of the sets (s, t, u, v) and (s', t', u', v'), we have

$$\mathrm{V}\Psi=\begin{vmatrix} (s-\alpha)(s'-\alpha'), & (s-\beta)(s'-\beta'), & (s-\gamma)(s'-\gamma'), & (s-\delta)(s'-\delta') \\ (t-\alpha)(t'-\alpha'), & (t-\beta)(t'-\beta'), & (t-\gamma)(t'-\gamma'), & (t-\delta)(t'-\delta') \\ (u-\alpha)(u'-\alpha'), & (u-\beta)(u'-\beta'), & (u-\gamma)(u'-\gamma'), & (u-\delta)(u'-\delta') \\ (v-\alpha)(v'-\alpha'), & (v-\beta)(v'-\beta'), & (v-\gamma)(v'-\gamma'), & (v-\delta)(v'-\delta') \end{vmatrix}$$

which gives various forms of the equation of homography. In particular, if $s=\alpha$, $s'=\beta'$, $t=\beta$, $t'=\alpha'$, $u=\gamma$, $u'=\delta'$, $v=\delta$, $v'=\gamma$, then

$$\mathrm{V}\Psi=\begin{vmatrix} . & . & (\alpha-\gamma)(\beta'-\gamma'), & (\alpha-\delta)(\beta'-\delta') \\ . & . & (\beta-\gamma)(\alpha'-\gamma'), & (\beta-\delta)(\alpha'-\delta') \\ (\gamma-\alpha)(\delta'-\alpha') & (\gamma-\beta)(\delta'-\beta') & . & . \\ (\delta-\alpha)(\gamma'-\alpha') & (\delta-\beta)(\gamma'-\beta') & . & . \end{vmatrix}$$

and the right-hand side breaks up into factors, which are equal to each other (whence also $\mathrm{V}=\Psi$), and the equation $\Psi=0$ takes the form

$$(\alpha-\gamma)(\beta-\delta)(\alpha'-\delta')(\beta'-\gamma')-(\alpha-\delta)(\beta-\gamma)(\alpha'-\gamma')(\beta'-\delta')=0,$$

which is, in fact, one of the equations which express the equality of the anharmonic ratios of $(\alpha, \beta, \gamma, \delta)$ and $(\alpha', \beta', \gamma', \delta')$.

115. In the case of a cubic, the expressions considered are—

$$(a, b, c, d \between x, y)^3, \qquad (1)$$

$$(ac-b^2,\ ad-bc,\ bd-c^2 \between x, y)^2, \qquad (2)$$

$$\left\{\begin{matrix} -a^2d+3abc-2b^3, \\ -abd+2ac^2-b^2c, \\ +acd-2b^2d+bc^2, \\ +ad^2-3bcd+2c^3 \end{matrix}\right\} \between x, y)^3, \qquad (3)$$

$$a^2d^2-6abcd+4ac^3+4b^3d-3b^2c^2, \qquad (4)$$

where (1) is the cubic, (2) is the quadricovariant or Hessian, (3) is the cubicovariant, and (4) is the quartinvariant or discriminant.

And where it is convenient to do so, I write

$$(1) = \mathrm{U},$$
$$(2) = \mathrm{H},$$
$$(3) = \Phi,$$
$$(4) = \square,$$

so that we have

$$\Phi^2 - \square\,\mathrm{U}^3 + 4\mathrm{H}^3 = 0.$$

116. The Hessian may be written under the form

$$(ax+by)(cx+dy)-(bx+cy)^2,$$

(which, indeed, is the form under which *quà* Hessian it is originally given), and under the form

$$\begin{vmatrix} y^2, & -yx, & x^2 \\ a, & b, & c \\ b, & c, & d \end{vmatrix}$$

The cubicovariant may be written under the form

$$\{2(ac-b^2)x+(ad-bc)y\}(bx^2+2cxy+dy^2)$$
$$-\{(ad-bc)x+2(bd-c^2)y\}(ax^2+2bxy+cy^2),$$

that is, as the Jacobian of the cubic and Hessian; and under the form

$$\tfrac{1}{2}(\partial_a, \partial_b, \partial_c, \partial_d \between y, -x)^3\,\square,$$

that is, as the evectant of the discriminant.

The discriminant, taken negatively, may be written under the form

$$+4(ac-b^2)(bd-c^2)-(ad-bc)^2,$$

that is, as the discriminant of the Hessian.

117. We have

$$(a, b, c, d \between bx^2+2cxy+dy^2, -ax^2-2bxy-cy^2)^3 = \mathrm{U}\Phi,$$

which expresses that a transmutant of the cubic is the product of the cubic and the cubicovariant. The equation

$$\{(\partial_a, \partial_b, \partial_c, \partial_d \between y, -x)^3\}^2 \square = 2\mathrm{U}^2$$

expresses that the second evectant of the discriminant is the square of the cubic.

The equation

$$\begin{vmatrix} d^2, & -3cd, & -3bd+6c^2, & -3bc+2ad \\ -3cd, & -3c^2+12bd, & -3ad-6bc, & -3ac+6b^2 \\ -3bd+6c^2, & -3ad-6bc, & -3b^2+12ac, & -3ab \\ -3bc-12ad, & -3ac+6b^2, & 3ab, & a^2 \end{vmatrix} = 27\square^2$$

expresses that the determinant formed with the second differential coefficients of the discriminant gives the square of the discriminant.

The covariants of the intermediate $\alpha\mathrm{U}+\beta\Phi$ are as follows, viz.—

118. For the Hessian, we have

$$\begin{aligned}\tilde{\mathrm{H}}(\alpha\mathrm{U}+\beta\Phi) &= (1, 0, -\square \between \alpha, \beta)^2\mathrm{H} \\ &= (\alpha^2-\beta^2\square)\mathrm{H};\end{aligned}$$

for the cubicovariant,

$$\begin{aligned}\tilde{\Phi}(\alpha\mathrm{U}+\beta\Phi) &= (0, \square, 0, -\square^2 \between \alpha, \beta)^2\mathrm{U} \\ &\quad +(1, 0, -\square, 0 \between \alpha, \beta)^2\Phi \\ &= (\alpha^2-\beta^2\square)(\alpha\Phi+\beta\square\mathrm{U});\end{aligned}$$

and for the discriminant,

$$\begin{aligned}\tilde{\square}(\alpha\mathrm{U}+\beta\Phi) &= (1, 0, -2\square, 0, \square^2 \between \alpha, \beta)^4\Phi \\ &= (\alpha^2-\beta^2\square)^2\square,\end{aligned}$$

where on the left-hand sides I have, for greater distinctness, written $\tilde{\mathrm{H}}$, &c. to denote the functional operation of taking the Hessian, &c. of the operand $\alpha\mathrm{U}+\beta\Phi$.

In particular, if $\alpha=0$, $\beta=1$,

$$\begin{aligned}\tilde{\mathrm{H}}\Phi &= -\square.\mathrm{H} \\ \tilde{\Phi}\Phi &= -\square^2.\mathrm{U} \\ \tilde{\square}\Phi &= \square^2.\end{aligned}$$

119. Solution of a cubic equation.

The question is to find a linear factor of the cubic

$$(a, b, c, d \between x, y)^3,$$

and this can be at once effected by means of the relation

$$\Phi^2 - \square\mathrm{U}^2 = -4\mathrm{H}^3$$

between the covariants. The equation in fact shows that each of the expressions

$$\tfrac{1}{2}(\Phi+\mathrm{U}\sqrt{\square}),\ \tfrac{1}{2}(\Phi-\mathrm{U}\sqrt{\square})$$

is a perfect cube, and consequently that the cube root of each of these expressions is a linear function of (x, y). The expression

$$\sqrt[3]{\tfrac{1}{2}(\Phi+\mathrm{U}\sqrt{\square})}-\sqrt[3]{\tfrac{1}{2}(\Phi-\mathrm{U}\sqrt{\square})}$$

is consequently a linear function of x, y, and it vanishes when $\mathrm{U}=0$, that is, the expression is a linear factor of the cubic.

It may be noticed here that the cubic being $a(x-\alpha y)(x-\beta y)(x-\gamma y)$, then we may write

$$\sqrt[3]{\tfrac{1}{2}(\Phi+\mathrm{U}\sqrt{\square})}-\sqrt[3]{\tfrac{1}{2}(\Phi-\mathrm{U}\sqrt{\square})}=\tfrac{1}{3}a(\omega-\omega^2)(\beta-\gamma)(x-\alpha y),$$

where ω is an imaginary cube root of unity: this will appear from the expressions which will be presently given for the covariants in terms of the roots.

120. Canonical form of the cubic.

The expressions $\tfrac{1}{2}(\Phi+\mathrm{U}\sqrt{\square})$, $\tfrac{1}{2}(\Phi-\mathrm{U}\sqrt{\square})$ are perfect cubes; and if we write

$$\tfrac{1}{2}(\Phi+\mathrm{U}\sqrt{\square})=\sqrt{\square}\,\mathrm{x}^3$$
$$\tfrac{1}{2}(\Phi-\mathrm{U}\sqrt{\square})=-\sqrt{\square}\,\mathrm{y}^3,$$

then we have

$$\mathrm{U}=\mathrm{x}^3+\mathrm{y}^3,$$
$$\Phi=\sqrt{\square}(\mathrm{x}^3-\mathrm{y}^3),$$

and thence also

$$\mathrm{H}=-\sqrt[3]{\square}\,\mathrm{xy}.$$

121. When the cubic is expressed in terms of the roots, we have

$$a^{-1}\mathrm{U}=(x-\alpha y)(x-\beta y)(x-\gamma y);$$

and then putting for shortness

$$\mathrm{A}=(\beta-\gamma)(x-\alpha y),$$
$$\mathrm{B}=(\gamma-\alpha)(x-\beta y),$$
$$\mathrm{C}=(\alpha-\beta)(x-\gamma y),$$

so that

$$\mathrm{A}+\mathrm{B}+\mathrm{C}=0,$$

we have

$$a^{-2}\mathrm{H}=-\tfrac{1}{18}(\mathrm{A}^2+\mathrm{B}^2+\mathrm{C}^2)=\tfrac{1}{9}(\mathrm{BC}+\mathrm{CA}+\mathrm{AB}),$$
$$a^{-3}\Phi=-\tfrac{1}{27}(\mathrm{B}-\mathrm{C})(\mathrm{C}-\mathrm{A})(\mathrm{A}-\mathrm{B}),$$
$$a^{-4}\square=-\tfrac{1}{27}(\beta-\gamma)^2(\gamma-\alpha)^2(\alpha-\beta)^2.$$

122. The covariants H, Φ are most simply expressed as above, but it may be proper to add the equations

$$a^{-3}\mathrm{H} = -\tfrac{1}{18}\Sigma(\beta-\gamma)^2(x-\alpha y)^2$$

$$= -\tfrac{1}{9}\left\{\begin{array}{l}\alpha^2+\beta^2+\gamma^2-\beta\gamma-\gamma\alpha-\alpha\beta,\\ 6\alpha\beta\gamma-\beta\gamma^2-\gamma\alpha^2-\alpha\beta^2-\beta^2\gamma-\gamma^2\alpha-\alpha^2\beta,\\ \beta^2\gamma^2+\gamma^2\alpha^2+\alpha^2\beta^2-\alpha^2\beta\gamma-\beta^2\gamma\alpha-\gamma^2\alpha\beta\end{array}\right\}(x,\ y)^2$$

$$= -\tfrac{1}{9}\{(\alpha+\omega\beta+\omega^2\gamma)x+(\beta\gamma+\omega\gamma\alpha+\omega^2\alpha\beta)y\}\{(\alpha+\omega^2\beta+\omega\gamma)x+(\beta\gamma+\omega^2\gamma\alpha+\omega\alpha\beta)y\}$$

(where ω is an imaginary cube root of unity),

$$a^{-3}\Phi = \tfrac{1}{27}\Sigma(\alpha-\beta)(\alpha-\gamma)^2(x-\beta y)^2(x-\gamma y)$$

$$= \left\{\begin{array}{l}2(\alpha^3+\beta^3+\gamma^3)-3(\beta\gamma^2+\gamma\alpha^2+\alpha\beta^2+\beta^2\gamma+\gamma^2\alpha+\alpha^2\beta)+12\alpha\beta\gamma,\\ -2(\alpha^2\beta\gamma+\beta^2\gamma\alpha+\gamma^2\alpha\beta)+4(\beta^2\gamma^2+\gamma^2\alpha^2+\alpha^2\beta^2)-(\beta\gamma^3+\gamma\alpha^3+\alpha\beta^3+\beta^3\gamma+\gamma^3\alpha+\alpha^3\beta),\\ -2(\alpha\beta^2\gamma^2+\beta\gamma^2\alpha^2+\gamma\alpha^2\beta^2)+4(\alpha^2\beta\gamma+\beta^2\gamma\alpha+\gamma^2\alpha\beta)-(\beta^2\alpha\gamma^3+\gamma^2\beta\alpha^3+\alpha^2\gamma\beta^3+\beta^3\alpha\gamma^2+\gamma^3\beta\alpha^2+\alpha^3\beta^2\gamma),\\ +2(\beta^3\gamma^3+\gamma^3\alpha^3+\alpha^3\beta^3)-3(\alpha\beta^2\gamma^3+\beta\gamma^2\alpha^3+\gamma\alpha^2\beta^3+\alpha\beta^3\gamma^2+\beta\gamma^3\alpha^2+\gamma\alpha^3\beta^2)+12\alpha^2\beta^2\gamma^2\end{array}\right\}(x,\ y)^3$$

$$= \{(2\alpha-\beta-\gamma)x+(2\beta\gamma-\gamma\alpha-\alpha\beta)y\}\{(2\beta-\gamma-\alpha)x+(2\gamma\alpha-\alpha\beta-\beta\gamma)y\}\{(2\gamma-\alpha-\beta)x+(2\alpha\beta-\beta\gamma-\gamma\alpha)y\}.$$

123. It may be observed that we have $a^{-6}\square\mathrm{U}^2 = -\tfrac{1}{27}\mathrm{A}^2\mathrm{B}^2\mathrm{C}^2$, which, with the above values of H, Φ in terms of A, B, C and the equation $\mathrm{A}+\mathrm{B}+\mathrm{C}=0$, verifies the equation $\Phi^2-\square\mathrm{U}^2+4\mathrm{H}^3=0$, which connects the covariants. In fact, we have identically,

$$(\mathrm{B}-\mathrm{C})^2(\mathrm{C}-\mathrm{A})^2(\mathrm{A}-\mathrm{B})^2 =$$
$$-4(\mathrm{A}+\mathrm{B}+\mathrm{C})^2\mathrm{ABC}+(\mathrm{A}+\mathrm{B}+\mathrm{C})^2(\mathrm{BC}+\mathrm{CA}+\mathrm{AB})^2+18(\mathrm{A}+\mathrm{B}+\mathrm{C})(\mathrm{BC}+\mathrm{CA}+\mathrm{AB})\mathrm{ABC}$$
$$-4(\mathrm{BC}+\mathrm{CA}+\mathrm{AB})^3-27\mathrm{A}^2\mathrm{B}^2\mathrm{C}^2,$$

by means of which the verification can be at once effected.

124. If, as before, ω is an imaginary cube root of unity, then we may write

$$27a^{-3}\Phi \quad = -(\mathrm{B}-\mathrm{C})(\mathrm{C}-\mathrm{A})(\mathrm{A}-\mathrm{B})$$
$$27a^{-3}\mathrm{U}\sqrt{\square} = \quad 3(\omega-\omega^2)\mathrm{ABC},$$

and these values give

$$27a^{-3}\tfrac{1}{2}(\Phi+\mathrm{U}\sqrt{\square}) = \{(\alpha+\omega^2\beta+\omega\gamma)\,x+(\beta\gamma+\omega^2\gamma\alpha+\omega\alpha\beta\,)y\}^3$$
$$27a^{-3}\tfrac{1}{2}(\Phi-\mathrm{U}\sqrt{\square}) = \{(\alpha+\omega\beta\,+\omega^2\gamma)x+(\beta\gamma+\omega\gamma\alpha\,+\omega^2\alpha\beta)y\}^3,$$

and we thence obtain

$$\sqrt[3]{\tfrac{1}{2}(\Phi+\mathrm{U}\sqrt{\square})}-\sqrt[3]{\tfrac{1}{2}(\Phi-\mathrm{U}\sqrt{\square})} = -\tfrac{1}{3}a(\omega-\omega^2)(\beta-\gamma)(x-\alpha y),$$

which agrees with a former result.

125. The preceding formulæ show without difficulty, that each factor of the cubicovariant is the harmonic of a factor of the cubic with respect to the other two factors of the cubic; and moreover, that the factors of the cubic and the cubicovariant form together an involution having for sibiconjugates the factors of the Hessian. In fact, the harmonic of $x-\alpha y$ with respect to $(x-\beta y)(x-\gamma y)$ is $(2\alpha-\beta-\gamma)x+(2\beta\gamma-\gamma\alpha-\alpha\beta)y$, which is a factor of the cubicovariant; the product of the pair of harmonic factors is

$$(2\alpha-\beta-\gamma)x^2+2(\beta\gamma-\alpha^2)xy+(-2\alpha\beta\gamma+\alpha^2\beta+\alpha^2\gamma)y^2;$$

and multiplying this by $\beta-\gamma$, and taking the sum of the analogous expressions, this sum vanishes, or the three pairs form an involution. That the Hessian gives the sibi-conjugates of the involution is most readily shown as follows:—the last-mentioned quadric may be written

$$\left(-(\alpha+\beta+\gamma)+3\alpha\right)x^2+2\left(\alpha\beta+\alpha\gamma+\beta\gamma-\alpha(\alpha+\beta+\gamma)\right)xy+\left(-3\alpha\beta\gamma+\alpha(\alpha\beta+\alpha\gamma+\beta\gamma)\right)y^2,$$

which is equal to

$$\left(3\frac{b}{a}+3\alpha\right)x^2+2\left(3\frac{c}{a}-3\frac{b}{a}\alpha\right)xy+\left(3\frac{d}{a}+3\frac{c}{a}\alpha\right)y^2,$$

or, throwing out the factor $3a^{-1}$, to

$$(b+a\alpha,\quad 2c-2b\alpha,\quad d+c\alpha\between x, y)^2,$$

which is harmonically related to the Hessian

$$(ac-b^2,\quad ad-bc,\quad bd-c^2\between x, y)^2;$$

and in like manner the other two pairs of factors will be also harmonically related to the Hessian.

126. In the case of a pair of equal roots, we have

$$\begin{aligned} a^{-1}\mathrm{U} &= \quad (x-\alpha y)^2(x-\gamma y),\\ a^{-2}\mathrm{H} &= -\tfrac{1}{9}(\alpha-\gamma)^2(x-\alpha y)^2,\\ a^{-3}\Phi &= -\tfrac{2}{27}(\alpha-\gamma)^3(x-\alpha y)^3,\\ \square &= \quad 0. \end{aligned}$$

And in the case of all the roots equal, we have

$$\begin{aligned} a^{-1}\mathrm{U} &= (x-\alpha y)^3,\\ \mathrm{H} &= 0,\quad \Phi=0,\quad \square=0. \end{aligned}$$

127. In the solution of a biquadratic equation we have to consider the cubic equation $\varpi^3-\mathrm{M}(\varpi-1)=0$. The cubic here is $(1, 0, -\mathrm{M}, \mathrm{M}\between \varpi, 1)^3$, or what is the same thing,

$$(1, 0, -\tfrac{1}{3}\mathrm{M}, \mathrm{M}\between \varpi, 1)^3;$$

the Hessian is

$$\mathrm{M}(-\tfrac{1}{3}, 1, -\tfrac{1}{9}\mathrm{M}\between \varpi, 1)^2;$$

the cubicovariant is

$$\mathrm{M}(-1, \tfrac{2}{9}\mathrm{M}, -\tfrac{1}{3}\mathrm{M}, \mathrm{M}+\tfrac{2}{27}\mathrm{M}^2\between \varpi, 1)^3;$$

and the discriminant is

$$\mathrm{M}^2(1-\tfrac{4}{27}\mathrm{M}).$$

128. In the case of a quartic, the expressions considered are—

$$(a, b, c, d, e\between x, y)^4, \tag{1}$$

$$ae-4bd+3c^2, \tag{2}$$

$$(ac-b^2, 2(ad-bc), ae+2bd-3c^2, 2(be-cd), ce-d^2\between x, y)^4, \tag{3}$$

$$ace+2bcd-ad^2-b^2e-c^3, \tag{4}$$

$$\left\{\begin{array}{l} -\ a^3d+3abc-2b^3, \\ -\ a^2e-2abd+9ac^2-6b^2c, \\ -\ 5abe+15acd-10b^2d, \\ +10ad^2-10b^2e, \\ +\ 5ade+10bd^2-15bce, \\ +\ ae^2+2bde-9c^2e+6cd^2, \\ +\ be^2-3cde+2d^3 \end{array}\right\}(x, y)^6, \qquad (5)$$

where (1) is the quartic, (2) is the quadrinvariant, (3) is the quadricovariant or Hessian, (4) is the cubinvariant, and (5) is the cubicovariant.

And where it is convenient to do so, I write

$$\begin{aligned} (1) &= \mathrm{U}, \\ (2) &= \mathrm{I}, \\ (3) &= \mathrm{H}, \\ (4) &= \mathrm{J}, \\ (5) &= \Phi. \end{aligned}$$

The preceding covariants are connected by the equation

$$\mathrm{JU}^3-\mathrm{IU}^2\mathrm{H}+4\mathrm{H}^3=-\Phi^2.$$

The discriminant is not an irreducible invariant, its value is

$$\square=\mathrm{I}^3-27\mathrm{J}^2=a^3e^3+\text{\&c.},$$

for which see Table No. 12.

129. It is for some purposes convenient to arrange the expanded expression of the discriminant in powers of the middle coefficient c. We thus have

$$\begin{aligned} \square= \ & a^3e^3-12a^2bde^2-27a^2d^4-6ab^2d^2e-27b^4e^2-64b^3d^3 \\ & +c(54a^2d^2e+54ab^2e^2+108abd^3+108b^3de) \\ & +c^2(-18a^2e^2-180abde+36b^2d^2) \\ & +c^3(-54ad^2-54b^2e) \\ & +c^4(81ae). \end{aligned}$$

130. Solution of a biquadratic equation.

We have to find a linear factor of the quartic

$$(a, b, c, d, e\between x, y)^4.$$

The equation $\mathrm{JU}^3-\mathrm{IU}^2\mathrm{H}+4\mathrm{H}^3=-\Phi^2$, putting for shortness

$$\mathrm{M}=\frac{\mathrm{I}^3}{4\mathrm{J}^2},$$

may be written

$$(1, 0, -\mathrm{M}, \mathrm{M}\between \mathrm{IH}, \mathrm{JU})^2=-\tfrac{1}{4}\mathrm{I}^3\Phi^2.$$

Hence, if $\varpi_1, \varpi_2, \varpi_3$ are the roots of

$$(1, 0, -\mathrm{M}, \mathrm{M}\between\varpi, 1)^3=0,$$

the expressions $\mathrm{IH}-\varpi_1\mathrm{JU}$, $\mathrm{IH}-\varpi_2\mathrm{JU}$, $\mathrm{IH}-\varpi_3\mathrm{JU}$ are each of them squares; write

$$(\varpi_2-\varpi_3)(\mathrm{IH}-\varpi_1\mathrm{JU})=\mathrm{X}^2,$$
$$(\varpi_3-\varpi_1)(\mathrm{IH}-\varpi_2\mathrm{JU})=\mathrm{Y}^2,$$
$$(\varpi_1-\varpi_2)(\mathrm{IH}-\varpi_3\mathrm{JU})=\mathrm{Z}^2,$$

so that, identically,

$$\mathrm{X}^2+\mathrm{Y}^2+\mathrm{Z}^2=0;$$

and consequently $\mathrm{X}+\imath\mathrm{Y}$, $\mathrm{X}-\imath\mathrm{Y}$ are each of them squares. The expression

$$\alpha\mathrm{X}+\beta\mathrm{Y}+\gamma\mathrm{Z}$$

will be a square if only

$$\alpha^2+\beta^2+\gamma^2=0,$$

which may be seen by writing it under the form

$$\tfrac{1}{2}(\alpha+\imath\beta)(\mathrm{X}-\imath\mathrm{Y})+\tfrac{1}{2}(\alpha-\imath\beta)(\mathrm{X}+\imath\mathrm{Y})-\gamma\imath\sqrt{\mathrm{X}^2+\mathrm{Y}^2};$$

and in particular, writing $\sqrt{\varpi_2-\varpi_3}$, $\sqrt{\varpi_3-\varpi_1}$, $\sqrt{\varpi_1-\varpi_2}$ for α, β, γ, the expression

$$(\varpi_2-\varpi_3)\sqrt{\mathrm{IH}-\varpi_1\mathrm{JU}}+(\varpi_3-\varpi_1)\sqrt{\mathrm{IH}-\varpi_2\mathrm{JU}}+(\varpi_1-\varpi_2)\sqrt{\mathrm{IH}-\varpi_3\mathrm{JU}}$$

is a square; and since the product of the different values is a multiple of U^3 (this is most readily perceived by observing that the expression vanishes for $\mathrm{U}=0$), the expression is the square of a linear factor of the quartic.

131. To complete the solution: $\varpi_1, \varpi_2, \varpi_3$ are the roots of the cubic equation

$$(1, 0, -\tfrac{1}{3}\mathrm{M}, \mathrm{M}\between\varpi, 1)^3=0;$$

and hence, putting for shortness,

$$\mathrm{P}^3=\tfrac{1}{2}\mathrm{M}\{(-1, \tfrac{2}{9}\mathrm{M}, -\tfrac{1}{3}\mathrm{M}, \mathrm{M}+\tfrac{2}{27}\mathrm{M}^2\between\mathrm{IH}, \mathrm{JU})^3+\sqrt{1-\tfrac{4}{27}\mathrm{M}}\,(1, 0, -\tfrac{1}{3}\mathrm{M}, \mathrm{M}\between\mathrm{IH}, \mathrm{JU})^3,$$
$$\mathrm{Q}^3=\tfrac{1}{2}\mathrm{M}\{(-1, \tfrac{2}{9}\mathrm{M}, -\tfrac{1}{3}\mathrm{M}, \mathrm{M}+\tfrac{2}{27}\mathrm{M}^2\between\mathrm{IH}, \mathrm{JU})^3-\sqrt{1-\tfrac{4}{27}\mathrm{M}}\,(1, 0, -\tfrac{1}{3}\mathrm{M}, \mathrm{M}\between\mathrm{IH}, \mathrm{JU})^3,$$

we have (ω being an imaginary cube root of unity).

$$\tfrac{1}{3}(\omega-\omega^2)(\varpi_2-\varpi_3)(\mathrm{IH}-\varpi_1\mathrm{JU})=\mathrm{P}-\mathrm{Q}.$$

And if

$$\mathrm{P}_0^3=\tfrac{1}{2}\mathrm{M}\{-1+\sqrt{1-\tfrac{4}{27}\mathrm{M}}\}$$
$$\mathrm{Q}_0^3=\tfrac{1}{2}\mathrm{M}\{-1-\sqrt{1-\tfrac{4}{27}\mathrm{M}}\},$$

then

$$\tfrac{1}{3}(\omega-\omega^2)(\varpi_2-\varpi_3)=\mathrm{P}_0-\mathrm{Q}_0.$$

Hence, multiplying and observing that $(\omega-\omega^2)^2=-3$, we find

$$-\frac{1}{(\omega-\omega^2)^2}(\varpi_2-\varpi_3)^2(\mathrm{IH}-\varpi_1\mathrm{JU})=(\mathrm{P}-\mathrm{Q})(\mathrm{P}_0-\mathrm{Q}_0),$$

and consequently

$$(\varpi_2-\varpi_3)\sqrt{\mathrm{IH}-\varpi_1\mathrm{JU}}=(\omega-\omega^2)\sqrt{-(\mathrm{P}-\mathrm{Q})(\mathrm{P}_0-\mathrm{Q}_0)}.$$

We have, in like manner,

$$\tfrac{1}{3}(\omega-\omega^2)(\varpi_2-\varpi_3)(\mathrm{IH}-\varpi_1\mathrm{JU})=\ \mathrm{P}-\mathrm{Q},$$
$$\tfrac{1}{3}(\omega-\omega^2)(\varpi_3-\varpi_1)(\mathrm{IH}-\varpi_2\mathrm{JU})=\omega\,\mathrm{P}-\omega^2\mathrm{Q},$$
$$\tfrac{1}{3}(\omega-\omega^2)(\varpi_1-\varpi_2)(\mathrm{IH}-\varpi_3\mathrm{JU})=\omega^2\mathrm{P}-\omega\mathrm{Q},$$

and

$$\tfrac{1}{3}(\omega-\omega^2)(\varpi_2-\varpi_3)=\ \mathrm{P}_0-\mathrm{Q}_0,$$
$$\tfrac{1}{3}(\omega-\omega^2)(\varpi_3-\varpi_1)=\omega\,\mathrm{P}_0-\omega^2\mathrm{Q}_0,$$
$$\tfrac{1}{3}(\omega-\omega^2)(\varpi_1-\varpi_2)=\omega^2\mathrm{P}_0-\omega\mathrm{Q}_0,$$

and therefore

$$(\varpi_2-\varpi_3)\sqrt{\mathrm{IH}-\varpi_1\mathrm{JU}}=(\omega-\omega^2)\sqrt{-(\mathrm{P}-\mathrm{Q})\quad(\mathrm{P}_0-\mathrm{Q}_0)},$$
$$(\varpi_3-\varpi_1)\sqrt{\mathrm{IH}-\varpi_2\mathrm{JU}}=(\omega-\omega^2)\sqrt{-(\omega\mathrm{P}-\omega^2\mathrm{Q})(\omega\mathrm{P}_0-\omega^2\mathrm{Q})},$$
$$(\varpi_3-\varpi_1)\sqrt{\mathrm{IH}-\varpi_3\mathrm{JU}}=(\omega-\omega^2)\sqrt{-(\omega^2\mathrm{P}-\omega\mathrm{Q})(\omega^2\mathrm{P}_0-\omega\mathrm{Q}_0)};$$

and hence disregarding the common factor $\omega-\omega^2$, the square of the linear factor of the quartic is

$$\sqrt{-(\mathrm{P}-\mathrm{Q})(\mathrm{P}_0-\mathrm{Q}_0)}+\sqrt{-(\omega\mathrm{P}-\omega^2\mathrm{Q})(\omega\mathrm{P}_0-\omega^2\mathrm{Q}_0)}+\sqrt{-(\omega^2\mathrm{P}-\omega\mathrm{Q})(\omega^2\mathrm{P}_0-\omega\mathrm{Q}_0)},$$

which is the required solution.

It may be proper to add that

$$-\varpi_1=\ \mathrm{P}_0+\ \mathrm{Q}_0,$$
$$-\varpi_2=\omega\,\mathrm{P}_0+\omega^2\mathrm{Q}_0,$$
$$-\varpi_3=\omega^2\mathrm{P}_0+\omega\,\mathrm{Q}_0.$$

132. The solution gives at once the canonical form of the quartic; in fact, writing

$$\mathrm{X}+\iota\mathrm{Y}=2\sqrt{(\varpi_2-\varpi_3)(\varpi_3-\varpi_1)}\sqrt{\mathrm{J}}\,\mathrm{x}^2,$$
$$\mathrm{X}-\iota\mathrm{Y}=2\sqrt{(\varpi_2-\varpi_3)(\varpi_3-\varpi_1)}\sqrt{\mathrm{J}}\,\mathrm{y}^2,$$

where X, Y have their former significations, we find, by a simple reduction,

$$\mathrm{IH}-\varpi_1\mathrm{JU}=\ \ (\varpi_2-\varpi_1)\mathrm{J}(\mathrm{x}^2+\mathrm{y}^2)^2$$
$$\mathrm{IH}-\varpi_2\mathrm{JU}=-(\varpi_2-\varpi_3)\mathrm{J}(\mathrm{x}^2-\mathrm{y}^2)^2$$
$$\mathrm{IH}-\varpi_3\mathrm{JU}=-\frac{(\varpi_2-\varpi_3)(\varpi_3-\varpi_1)}{\varpi_1-\varpi_2}\,\mathrm{J}\,.\,4\mathrm{x}^2\mathrm{y}^2,$$

and thence putting

$$\theta=-\frac{\varpi_2}{\varpi_1-\varpi_2}=\frac{\tfrac{1}{3}(\omega-\omega^2)(\omega^2\mathrm{P}_0+\omega\mathrm{Q}_0)}{(\omega^2\mathrm{P}_0-\omega\mathrm{Q}_0)},$$

we have

$$\mathrm{U}=\mathrm{x}^4+\mathrm{y}^4+6\theta\mathrm{x}^2\mathrm{y}^2,$$

which is the form required.

133. The Hessian may be written under the form

$$(\partial_x,\ -\partial_y,\ \partial_x,\ -\partial_y,\ \partial_x)^4(x,\ y)^4\mathrm{J},$$

that is, as the evectant of the cubinvariant.

The cubicovariant may be obtained by writing the quartic under the form

$$(ax+by,\ bx+cy,\ cx+dy,\ dx+ey\between x,\ y)^3$$

and treating the linear functions as coefficients, or considering this as a cubic, the cubicovariant of the cubic gives the cubicovariant of the quartic.

If we represent the cubicovariant by

$$\Phi=(\mathrm{a,\ b,\ c,\ d,\ e,\ f,\ g}\between x,\ y)^6,$$

then we have identically,

$$\mathrm{ag-9ce+8d^2=0};$$

and moreover forming the quadrinvariant of the sextic, we find

$$\mathrm{ag-6bf+15ce-10d^2}=\tfrac{1}{6}\square,$$

where $\square$ is the discriminant of the quartic. From these two equations we find

$$\mathrm{bf-4ce+3d^2}=-\tfrac{1}{36}\square,$$

which is an expression given by Mr. SALMON: it is the more remarkable as the left-hand side is the quadrinvariant of $(\mathrm{b,\ c,\ d,\ e,\ f}\between x,\ y)^4$, which is *not* a covariant of the quartic. It may be noticed also that we have

$$\mathrm{af-3be+2cd=0}$$
$$\mathrm{bg-3cf+2de=0}.$$

134. The covariants of the intermediate

$$\alpha\mathrm{U}+6\beta\mathrm{H}$$

of the quartic and Hessian are as follows, viz.—

The quadrinvariant is

$$\tilde{\mathrm{I}}(\alpha\mathrm{U}+6\beta\mathrm{H})=(\mathrm{I,\ 18J,\ 3I^2}\between\alpha,\ \beta)^2;$$

the cubinvariant is

$$\tilde{\mathrm{J}}(\alpha\mathrm{U}+6\beta\mathrm{H})=(\mathrm{J,\ I^2,\ 9IJ,\ -I^3+54J^2}\between\alpha,\ \beta)^3;$$

the Hessian is

$$\tilde{\mathrm{H}}(\alpha\mathrm{U}+6\beta\mathrm{H})=(1,\ 0,\ -3\mathrm{I}\between\alpha,\ \beta)^2\mathrm{H}$$
$$+(0,\ \mathrm{I},\ \ 9\mathrm{J}\between\alpha,\ \beta)^2\mathrm{U};$$

and the cubicovariant is

$$\tilde{\Phi}(\alpha\mathrm{U}+6\beta\mathrm{H})=(1,\ 0,\ -9\mathrm{I},\ -54\mathrm{J}\between\alpha,\ \beta)^3\Phi;$$

to which may be added the discriminant, which is

$$\tilde{\square}(\alpha\mathrm{U}+6\beta\mathrm{H})=(1,\ 0,\ -18\mathrm{I},\ 108\mathrm{J},\ 81\mathrm{I^2},\ 972\mathrm{IJ},\ -2916\mathrm{J^2}\between\alpha,\ \beta)^6\square.$$

135. The expression for the lambdaic is

$$\begin{vmatrix} a & , & b & , & c-2\lambda \\ b & , & c+\lambda, & & d \\ c-2\lambda, & & d & , & e \end{vmatrix}=\mathrm{J}+\lambda\mathrm{I}-4\lambda^3.$$

If the determinant is represented by Λ, that is if

$$\Lambda=-4\lambda^3+\lambda\mathrm{I}+\mathrm{J},$$

then if λ_1, λ_2, λ_3 are the roots of the equation $\Lambda=0$, and if the values of $\partial_\alpha\Lambda$, &c. obtained by writing λ_i in the place of λ are represented by $\partial_\alpha\Lambda_i$, &c., then if x, y satisfy the

FRANKLIN INSTITUTE LIBRARY

equation $$(a, b, c, d, e\between x, y)^4=0,$$
we have identically (X, Y being arbitrary),

$$\begin{aligned}\frac{(a, b, c, d, e\between X, Y\between x, y)^3}{Xy-Yx}&=\sqrt{-(\partial_c, -\partial_d, \partial_e, -\partial_b, \partial_a\between X, Y)^4\Lambda_1}\\&+\sqrt{-(\partial_c, -\partial_d, \partial_e, -\partial_b, \partial_a\between X, Y)^4\Lambda_2}\\&+\sqrt{-(\partial_c, -\partial_d, \partial_e, -\partial_b, \partial_a\between X, Y)^4\Lambda_3},\end{aligned}$$

a theorem due to ARONHOLD. I have quoted this theorem in its original form as an application of the lambdaic, but I remark that

$$-(\partial_c, -\partial_d, \partial_e, -\partial_b, \partial_a\between X, Y)^4\Lambda=-\lambda(a, \ldots\between X, Y)^4-(ac-b^2, \ldots\between X, Y)^4=-\lambda U'-H'$$

if U′, H′ are what U, H become, substituting for (x, y) the new facients (X, Y). Moreover, we have

$$\lambda=-\frac{J\varpi}{I};$$

for substituting this value in the equation $\Lambda=0$, we obtain the before-mentioned equation $\varpi^3-M(\varpi-1)=0$. We have, therefore,

$$-(\partial_c, -\partial_d, \partial_e, -\partial_b, \partial_a\between X, Y)^4\Lambda=\frac{J\varpi}{I}U'-H'=-\frac{1}{I}(IH'-J\varpi U'),$$

and the equation becomes

$$\frac{(a, b, c, d, e\between X, Y\between x, y)^3}{Xy-Yx}\sqrt{-I}=\sqrt{IH'-J\varpi_1U'}+\sqrt{IH'-J\varpi_2U'}+\sqrt{IH'-J\varpi_3U'}.$$

Moreover, if $(x-\alpha y)$ be a factor of the quartic, then replacing in the formula y by the value αx, (x, y) will disappear altogether; and then changing (X, Y) into (x, y) where x, y are now arbitrary, we have

$$\frac{(a, b, c, d, e\between x, y\between \alpha, 1)^3}{x-\alpha y}\sqrt{-I}=\sqrt{IH-\varpi_1JU}+\sqrt{IH-\varpi_2JU}+\sqrt{IH-\varpi_3JU},$$

which is a form connected with the results in Nos. 130 and 131.

136. We have

$$\begin{vmatrix} y^4, & -4xy^3, & 6x^2y^2, & -4x^3y, & x^4 \\ & a\ , & 3b\ , & 3c\ , & d \\ a\ , & 3b\ , & 3c\ , & d\ , & \\ & b\ , & 3c\ , & 3d\ , & e \\ b\ , & 3c\ , & 3d\ , & e\ , & \end{vmatrix}=6IH-9JU;$$

it will appear from the formulæ relating to the roots of the quartic, that the expression $6IH-9JU$ vanishes identically when there are two pairs of equal roots, or what is the same thing, when the quartic is a perfect square. The conditions in order that the expression may vanish are obviously

$$\begin{aligned}&6(ac-b^2):3(ad-bc):ae+2bd-3c^2:3(be-cd):6(ce-d^2):9J\\=\ &a\ :\ b\ :\ c\ :\ d\ :\ e\ :\ I,\end{aligned}$$

conditions which imply that the several determinants

$$\left\| \begin{matrix} 6(ac-b^2), & 3ad-bc, & ae+2bd-3c^2, & 3(be-cd), & 6(ce-d^2) \\ a\ , & b\ , & c\ , & d\ , & e \end{matrix} \right\|,$$

all of them vanish. If for a moment we write $6\mathrm{H}=(a', b', c', d', e')(x, y)^4$, then the determinants are

$$\left\| \begin{matrix} a', & b', & c', & d', & e' \\ a, & b, & c, & d, & e \end{matrix} \right\|,$$

we have identically

$$\begin{aligned} ad'-a'd &= 3(bc'-b'c), \\ eb'-e'b &= 3(dc'-d'c), \\ ae'-a'e &= 3(bd'-b'd), \end{aligned}$$

and the ten determinants thus reduce themselves to seven determinants only, these in fact being, to mere numerical factors *près*, the coefficients of the cubicovariant; this perfectly agrees with a subsequent result, viz. that the cubicovariant vanishes identically when the quartic is a perfect square.

137. It may be remarked that the equation $6\mathrm{IH}-9\mathrm{JU}=0$ will be satisfied identically if

$$a=\frac{b^2}{c-\varphi},\ e=\frac{d^2}{c-\varphi},\ bd=(c-\varphi)(c+2\varphi),$$

where φ is arbitrary; the quartic is in this case the square of

$$\left(\frac{b}{\sqrt{c-\varphi}}, \sqrt{c-\varphi}, \frac{d}{\sqrt{c-\varphi}}\right)(x, y)^2.$$

If with the conditions in question we combine the equation $\mathrm{I}=0$ (which in this case implies also $\mathrm{J}=0$), we obtain $\varphi=0$, and consequently

$$\frac{a}{b}=\frac{b}{c}=\frac{c}{d}=\frac{d}{e},$$

or the quartic will be a complete fourth power.

It is easy to express in terms of the coefficients a', b', c', d', e' of $6\mathrm{H}$ the different determinants

$$\left\| \begin{matrix} a, & b, & c, & d \\ b, & c, & d, & e \end{matrix} \right\|,$$

we have in fact

$$\left\{ \begin{aligned} ae-bd &= \tfrac{1}{2}\left(c'+\frac{1}{\sqrt{3}}\sqrt{a'e'+4b'd'-3c'^2}\right), \\ 3(bd-c^2) &= \tfrac{1}{2}\left(c'-\frac{1}{\sqrt{3}}\sqrt{a'e'+4b'd'-3c'^2}\right), \\ ac-b^2 &= \tfrac{1}{6}a', \\ ad-bc &= \tfrac{1}{3}b', \\ be-cd &= \tfrac{1}{3}c', \\ ce-d^2 &= \tfrac{1}{6}e', \end{aligned} \right.$$

whence all the above-mentioned determinants will vanish, or the quartic will be a perfect fourth power if only the Hessian vanishes identically.

138. Considering the quartic as expressed in terms of the roots, we have

$$a^{-1}U=(x-\alpha y)(x-\beta y)(x-\gamma y)(x-\delta y);$$

and if we write for shortness

$$A=(\beta-\gamma)(\alpha-\delta),$$
$$B=(\gamma-\alpha)(\beta-\delta),$$
$$C=(\alpha-\beta)(\gamma-\delta),$$

which are connected by

$$A+B+C=0,$$

then we have

$$a^{-2}I=\tfrac{1}{24}(A^2+B^2+C^2)=-\tfrac{1}{12}(BC+CA+AB),$$
$$a^{-3}J=\tfrac{1}{432}(B-C)(C-A)(A-B);$$

and for the discriminant we have

$$a^{-6}\square=\tfrac{1}{256}(\alpha-\beta)^2(\alpha-\gamma)^2(\alpha-\delta)^2(\beta-\gamma)^2(\beta-\delta)^2(\gamma-\delta)^2$$
$$=\tfrac{1}{256}A^2B^2C^2,$$

and it is easy by means of a preceding formula to verify the equation $\square=I^3-27J^2$.

139. The formulæ show a very remarkable analogy between the covariants of a cubic and the invariants of a quartic. In fact—

For the cubic.	For the quartic.
$\begin{cases} A=(\beta-\gamma)(x-\alpha y), \\ B=(\gamma-\alpha)(x-\beta y), \\ C=(\alpha-\beta)(x-\gamma y), \end{cases}$	$\begin{cases} A=(\beta-\gamma)(\alpha-\delta), \\ B=(\gamma-\alpha)(\beta-\delta), \\ C=(\alpha-\beta)(\gamma-\delta). \end{cases}$

And then we have corresponding to each other—

For the cubic.	For the quartic.
The Hessian,	The quadrinvariant,
The cubicovariant,	The cubinvariant,
The cubic into the square root of the discriminant.	The discriminant.

140. For the two covariants, we have

$$a^{-2}H=-\tfrac{1}{48}\Sigma(\alpha-\beta)^2(x-\gamma y)^2(x-\delta y)^2,$$

and

$$a^{-3}\Phi=-\tfrac{1}{32}\mathfrak{A}\mathfrak{B}\mathfrak{C},$$

if for shortness,

$$\mathfrak{A}=(\delta+\alpha-\beta-\gamma,\quad -\delta\alpha+\beta\gamma,\quad \delta\alpha(\beta+\gamma)-\beta\gamma(\delta+\alpha)\between x, y)^2,$$
$$\mathfrak{B}=(\delta+\beta-\gamma-\alpha,\quad -\delta\beta+\gamma\alpha,\quad \delta\beta(\gamma+\alpha)-\gamma\alpha(\delta+\beta)\between x, y)^2,$$
$$\mathfrak{C}=(\delta+\gamma-\alpha-\beta,\quad -\delta\gamma+\alpha\beta,\quad \delta\gamma(\alpha+\beta)-\alpha\beta(\delta+\gamma)\between x, y)^2.$$

141. We have

$$M=\tfrac{27}{8}\frac{(A^2+B^2+C^2)^3}{(B-C)^2(C-A)^2(A-B)^2};$$

or putting for shortness

$$\Lambda=\tfrac{3}{2}\frac{A^2+B^2+C^2}{(B-C)(C-A)(A-B)},$$

we have

$$M=\tfrac{3}{2}(A^2+B^2+C^2)\Lambda^2;$$

and it is then easy to deduce

$$\varpi_1=\Lambda(B-C)$$
$$\varpi_2=\Lambda(C-A)$$
$$\varpi_3=\Lambda(A-B);$$

in fact, these values give

$$\begin{aligned}\varpi_1+\varpi_2+\varpi_3 &= 0\\ \varpi_1\varpi_2+\varpi_1\varpi_3+\varpi_2\varpi_3 &= -M\\ \varpi_1\varpi_2\varpi_3 &= M,\end{aligned}$$

and they are consequently the roots of the equation $\varpi^3-M(\varpi-1)=0$.

142. The leading coefficient of $IH-\varpi_1JU$ is then equal to a^4 into the following expression, viz.

$$\tfrac{1}{24}(A^2+B^2+C^2)a^{-2}(ac-b^2)-\tfrac{1}{288}(A^2+B^2+C^2)(B-C),$$

which is equal to

$$\tfrac{1}{1152}(A^2+B^2+C^2)\{48a^{-2}(ac-b^2)-4(B-C)\},$$

and the term in {} is

$$8(\alpha\beta+\alpha\gamma+\alpha\delta+\beta\gamma+\beta\delta+\gamma\delta)-3(\alpha+\beta+\gamma+\delta)^2-4(\gamma-\alpha)(\beta-\delta)+4(\alpha-\beta)(\gamma-\delta),$$

which is equal to

$$-3(\delta+\alpha-\beta-\gamma)^2.$$

But $IH-\varpi_1JU$ is a square, and it is easy to complete the expression, and we have

$$a^{-4}(IH-\varpi_1JU)=-\tfrac{1}{384}(A^2+B^2+C^2)\{(\delta+\alpha-\beta-\gamma,\ -\delta\alpha+\beta\gamma,\ \delta\alpha(\beta+\gamma)-\beta\gamma(\delta+\alpha)\between x,y)^2\}^2,$$
$$a^{-4}(IH-\varpi_2JU)=-\tfrac{1}{384}(A^2+B^2+C^2)\{(\delta+\beta-\gamma-\alpha,\ -\delta\beta+\gamma\alpha,\ \delta\beta(\gamma+\alpha)-\gamma\alpha(\delta+\beta)\between x,y)^2\}^2,$$
$$a^{-4}(IH-\varpi_3JU)=-\tfrac{1}{384}(A^2+B^2+C^2)\{(\delta+\gamma-\alpha-\beta,\ -\delta\gamma+\alpha\beta,\ \delta\gamma(\alpha+\beta)-\alpha\beta(\gamma+\delta)\between x,y)^2\}^2.$$

We have, moreover,

$$\varpi_2-\varpi_3=-3\Lambda A,$$
$$\varpi_3-\varpi_1=-3\Lambda B,$$
$$\varpi_1-\varpi_2=-3\Lambda C,$$

and thence

$$a^{-2}(\varpi_2-\varpi_3)\sqrt{IH-\varpi_1JU}=\tfrac{1}{8}(\omega-\omega^2)\frac{A^2+B^2+C^2}{(B-C)(C-A)(A-B)}(\beta-\gamma)(\alpha-\delta)$$
$$\times(\delta+\alpha-\beta-\gamma,\ -\delta\alpha+\beta\gamma,\ \delta\alpha(\beta+\gamma)-\beta\gamma(\delta+\alpha)\between x,y)^2.$$

And taking the sum of the analogous expressions, we find

$$a^{-2}\{(\varpi_2-\varpi_3)\sqrt{IH-\varpi_1JU}+(\varpi_3-\varpi_1)\sqrt{IH-\varpi_2JU}+(\varpi_1-\varpi_2)\sqrt{IH-\varpi_3JU}\}$$
$$=-\tfrac{1}{4}(\omega-\omega^2)\frac{A^2+B^2+C^2}{(B-C)(C-A)(A-B)}(\alpha-\beta)(\beta-\gamma)(\gamma-\alpha)(x-\delta y)^2,$$

which agrees with a former result.

143. The equation $I=0$ gives

$$A:B:C=1:\omega:\omega^2,$$

where ω is an imaginary cube root of unity; the factors of the quartic may be said in this case to be *Symmetric Harmonics*.

The equation $J=0$ gives one of the three equations,

$$A=B,\quad B=C,\quad C=A;$$

in this case a pair of factors of the quartic are harmonics with respect to the other pair of factors. If we have simultaneously $I=0$, $J=0$, then

$$A=B=C=0,$$

and in this case three of the factors of the quartic are equal.

144. If any two of the linear factors of the quartic are considered as forming, with the other two linear factors, an involution, the sibiconjugates of the involution make up a quadratic factor of the cubicovariant; and considering the three pairs of sibiconjugates, or what is the same thing, the six linear factors of the cubicovariant, the factors of a pair are the sibiconjugates of the involution formed by the other two pairs of factors.

In fact, the sibiconjugates of the involution formed by the equations

$$(x-\alpha y)(x-\delta y)=0,\quad (x-\beta y)(x-\gamma y)=0$$

are found by means of the Jacobian of these two functions, viz. of the quadrics

$$(2,\ -\delta-\alpha,\ 2\delta\alpha\between x,y)^2$$
$$(2,\ -\beta-\gamma,\ 2\beta\gamma\between x,y)^2,$$

which is

$$(\delta+\alpha-\beta-\gamma,\ -\delta\alpha+\beta\gamma,\ \delta\alpha(\beta+\gamma)-\beta\gamma(\delta+\alpha)\between x,y)^2,$$

viz. a quadratic factor of the cubicovariant; and forming the other two factors, there is no difficulty in seeing that any one of these is the Jacobian of the other two.

145. In the case of a pair of equal roots, we have

$$\begin{aligned}
a^{-1}U &= (x-\alpha y)^2(x-\gamma y)(x-\delta y),\\
a^{-2}I &= \tfrac{1}{12}(\alpha-\gamma)^2(\alpha-\delta)^2,\\
a^{-3}J &= -\tfrac{1}{216}(\alpha-\gamma)^2(\alpha-\delta)^3,\\
\square &= 0,\\
a^{-2}H &= -\tfrac{1}{48}\{2(\alpha-\gamma)^2(x-\delta y)^2+2(\alpha-\delta)^2(x-\gamma y)^2+(\gamma-\delta)^2(x-\alpha y)^2\}(x-\alpha y)^2,\\
a^{-3}\Phi &= \tfrac{1}{12}(\gamma-\delta)^2(2\alpha-\gamma-\delta,\ \gamma\delta-\alpha^2,\ \gamma\alpha^2+\delta\alpha^2-2\gamma\alpha\delta\between x,y)^2(x-\alpha y)^4.
\end{aligned}$$

In the case of two pairs of equal roots, we have

$$\begin{aligned}
a^{-1}U &= (x-\alpha y)^2(x-\gamma y)^2,\\
a^{-2}I &= \tfrac{1}{12}(\alpha-\gamma)^4,\\
a^{-3}J &= -\tfrac{1}{216}(\alpha-\gamma)^6,\\
\square &= 0,\\
a^{-1}H &= -\tfrac{1}{12}(\alpha-\gamma)^2(x-\alpha y)^2(x-\gamma y)^2,\\
\Phi &= 0;
\end{aligned}$$

these values give also

$$6\mathrm{IH}-9\mathrm{JU}=0.$$

146. In the case of three equal roots, we have

$$\begin{aligned} a^{-1}\mathrm{U} &= (x-\alpha y)^3(x-\delta y), \\ \mathrm{I} &= 0,\ \mathrm{J}=0,\ \square=0, \\ a^{-3}\mathrm{H} &= -\tfrac{1}{48}(\alpha-\delta)^2\{2(x-\delta y)^2+(x-\alpha y)^2\}(x-\alpha y)^2, \\ a^{-3}\Phi &= \tfrac{1}{32}(\alpha-\delta)^2(x-\alpha y)^6; \end{aligned}$$

and in the case of four equal roots, we have

$$\begin{aligned} a^{-1}\mathrm{U} &= (x-\alpha y)^4, \\ \mathrm{I} &= 0,\ \mathrm{J}=0,\ \square=0, \\ \mathrm{H} &= 0,\ \Phi=0. \end{aligned}$$

The preceding formulæ, for the case of equal roots, agree with the results obtained in my memoir on the conditions for the existence of given systems of equalities between the roots of an equation.

Addition, 7th October, 1858.

Covariant and other Tables (binary quadrics Nos. 25 bis, 29 A, 49 A, and 50 bis).

Mr. SALMON has pointed out to me, that in the Table No. 25 of the simplest octinvariant of a binary quintic*, the coefficients -210, -17, $+18$ and $+38$ are erroneous, and has communicated to me the corrected values, which I have since verified: the terms, with the corrected values of the coefficients, are—

No. 25 bis.

		$-220\ abc^3d^2ef$ $-\ 27\ ac^5f^2$	$+22\ b^4d^2f^2$	$+74\ bc^3d^3e$

Mr. SALMON has also performed the laborious calculation of HERMITES' 18-thic invariant of a binary quintic, and has kindly permitted me to publish the result, which is given in the following Table:—

No. 29 A.

$+\ 1\ a^7d^3f^6$	$+60\ a^6bcd^3e^2f^4$	$-10\ a^6bd^3e^2f^2$	$+120\ a^5c^3de^4f^4$	$-\ 15\ a^5cd^3f^5$
$-\ 5\ a^7d^2e^2f^5$	$-90\ a^6bcd^2e^4f^4$	$-10\ a^6bde^3f$	$-\ 40\ a^5c^3e^4f^3$	$-110\ a^5cd^2e^2f^4$
$+10\ a^7d^2e^4f^4$	$+60\ a^6bcde^6f^3$	$+\ 5\ a^6be^{11}$	$+\ 60\ a^5c^3d^2ef^5$	$+265\ a^5cd^2e^4f^3$
$-10\ a^7d^2e^6f^3$	$-15\ a^6bce^8f^2$	$-\ 1\ a^5c^5f^7$	$+\ 30\ a^5c^3d^3e^2f^4$	$-200\ a^5cd^2e^6f^2$
$+\ 5\ a^7de^8f^2$	$+10\ a^5bd^3ef^6$	$+15\ a^5c^4def^6$	$-180\ a^5c^3d^2e^4f^3$	$+\ 65\ a^5cd^2e^8f$
$-\ 1\ a^7e^{10}f$	$-35\ a^5bd^2e^2f^4$	$-10\ a^5c^4e^3f^5$	$+120\ a^5c^3de^7f^2$	$-\ 10\ a^5cde^{10}$
$-15\ a^6bcd^4f^6$	$+40\ a^5bd^2e^4f^3$	$-90\ a^5c^3d^2e^2f^5$	$-\ 20\ a^5c^3e^9f$	$+\ 45\ a^5d^2ef^4$

* Second Memoir, Philosophical Transactions, t. cxlvi. (1856) p. 125.

No. 29 A (continued).

− 100	$a^2d^2e^2f^3$	− 980	$a^2c^2d^2e^2f^2$	+ 2310	$a^2b^2cd^2e^2f^2$	+ 10	$a^3b^2c^2f^7$
+ 81	$a^2d^2e^2f^3$	+ 1320	$a^2c^2d^2ef$	+ 1795	$a^2b^2cd^2ef$	− 60	$a^3b^2cedef^6$
− 30	$a^2d^2e^2f$	− 260	$a^2c^2de^2$	− 1800	$a^2b^2cd^2e^3$	+ 40	$a^3b^2ce^2f^5$
+ 5	$a^2d^2e^3$	+ 60	$a^2c^2df^4$	+ 240	$a^2b^2d^2ef^3$	+ 40	$a^3b^2d^3f^5$
+ 10	$a^2b^2d^2f^4$	− 500	$a^2c^2d^2e^2f^3$	+ 30	$a^2b^2d^2e^2f^2$	− 30	$a^3b^2d^2e^2f^5$
− 40	$a^2b^2d^2e^2f^4$	+ 2235	$a^2c^2d^2ef^2$	− 870	$a^2b^2d^2ef$	− 40	$a^3b^2c^2ef^6$
+ 60	$a^2b^2d^2e^2f^4$	− 1995	$a^2c^2d^2ef$	+ 615	$a^2b^2d^2e^3$	+ 180	$a^3b^2c^2d^2f^5$
− 40	$a^2b^2de^2f^3$	+ 370	$a^2c^2d^2e^3$	− 45	$a^2be^2f^3$	− 360	$a^3b^2c^2def^5$
+ 10	$a^2b^2e^2f^3$	+ 360	$a^2cd^2ef^3$	− 310	$a^2bc^2def^5$	+ 240	$a^3b^2c^2ef^4$
+ 5	$a^2b^2e^2f^7$	− 1320	$a^2cd^2ef^2$	+ 685	$a^2bc^2d^2f^4$	+ 360	$a^3b^2cd^2ef^4$
− 60	$a^2b^2c^2def^6$	+ 1110	a^2cd^2ef	+ 120	$a^2bc^2d^2f^3$	− 360	$a^3b^2cd^2e^2f^4$
+ 40	$a^2b^2c^2e^2f^5$	− 210	$a^2cd^2e^3$	+ 1965	$a^2bc^2d^2e^2f^4$	− 196	$a^3b^2d^2f^5$
+ 90	$a^2b^2c^2d^2f^6$	− 81	$a^2d^2e^2f^3$	− 2210	$a^2bc^2de^2f^3$	− 660	$a^3b^2d^2e^2f^4$
− 90	$a^2b^2c^2def^4$	+ 270	$a^2d^2e^2f^2$	− 960	$a^2bc^2e^2f^3$	+ 1840	$a^3b^2d^2e^2f^3$
+ 30	$a^2b^2c^2e^2f^3$	− 225	a^2d^2ef	− 11700	$a^2bc^2d^2e^2f^2$	− 1040	$a^3b^2d^2ef^3$
− 210	$a^2b^2cd^2ef^4$	+ 45	$a^2d^2e^3$	+ 15435	$a^2bc^2d^2ef^2$	− 180	$a^3b^2de^2f$
+ 120	$a^2b^2cd^2e^2f^4$	− 10	$a^2b^2c^2f^7$	− 2760	a^2bc^2def	+ 216	$a^3b^2e^{10}$
+ 360	$a^2b^2cd^2ef^3$	+ 90	$a^2b^2c^2def^6$	+ 555	$a^2bc^2e^3$	− 265	$a^3b^2c^2df^6$
− 420	$a^2b^2cde^2f^3$	− 60	$a^2b^2c^2e^2f^5$	− 780	$a^2bc^2d^2f^4$	+ 315	$a^3b^2c^2e^2f^5$
+ 130	$a^2b^2ce^2f$	− 120	$a^2b^2cd^2f^5$	+ 14040	$a^2bc^2d^2e^2f^3$	+ 180	$a^3b^2c^2d^2ef^5$
− 5	$a^2b^2d^2f^5$	+ 90	$a^2b^2cd^2e^2f^4$	− 10625	$a^2bc^2d^2ef^2$	+ 1700	$a^3b^2c^2def^4$
+ 195	$a^2b^2d^2e^2f^4$	+ 110	$a^2b^2d^2ef^3$	− 3220	$a^2bc^2d^2ef$	− 1840	$a^3b^2c^2e^2f^3$
− 315	$a^2b^2d^2e^3f^3$	− 50	$a^2b^2d^2e^2f^4$	− 570	$a^2bc^2d^2e^3$	− 615	$a^3b^2c^2df$
+ 40	$a^2b^2d^2ef^2$	− 240	$a^2b^2d^2e^2f^3$	− 5840	$a^2bc^2d^2ef^3$	− 1350	$a^3b^2c^2d^2ef^4$
+ 165	$a^2b^2d^2ef$	+ 280	$a^2b^2de^2f^3$	− 540	$a^2bc^2d^2e^2f^2$	+ 1560	$a^3b^2c^2de^2f^3$
− 75	$a^2b^2de^{10}$	− 90	$a^2b^2e^2f$	+ 5550	$a^2bc^2d^2ef$	+ 135	$a^3b^2c^2e^2f$
− 10	$a^2bc^2ef^6$	+ 35	$a^2b^2c^2ef^6$	+ 1285	$a^2bc^2d^2e^3$	+ 2210	$a^3b^2cd^2ef^4$
− 60	$a^2bc^2d^2f^6$	− 30	$a^2b^2c^2d^2f^6$	+ 990	$a^2bcd^2f^3$	− 4100	$a^3b^2cd^2e^2f^3$
+ 210	$a^2bc^2de^2f^5$	− 120	$a^2b^2c^2de^2f^5$	+ 3150	$a^2bcd^2e^2f^2$	+ 6000	$a^3b^2cd^2ef^2$
− 110	$a^2bc^2e^2f^4$	+ 50	$a^2b^2c^2ef^4$	− 3600	a^2bcd^2ef	− 4880	$a^3b^2cd^2e^2f$
+ 60	$a^2bc^2d^2ef^4$	− 60	$a^2b^2c^2d^2ef^5$	− 615	$a^2bcd^2e^3$	+ 990	$a^3b^2cde^3$
− 360	$a^2bc^2de^2f^3$	+ 360	$a^2b^2c^2def^3$	− 945	$a^2bd^{10}ef^3$	− 25	$a^3b^2df^4$
+ 240	$a^2bc^2e^2f^3$	− 210	$a^2b^2c^2e^2f^2$	+ 900	a^2bd^2ef	+ 3710	$a^3b^2d^2ef^3$
+ 30	$a^2bc^2d^2f^4$	+ 270	$a^2b^2cd^2f^4$	+ 45	$a^2bd^2e^3$	− 10755	$a^3b^2d^2e^2f^2$
− 210	$a^2bc^2d^2e^2f^4$	+ 575	$a^2b^2cd^2e^2f^4$	+ 180	$a^2c^2ef^3$	+ 9875	$a^3b^2d^2ef$
− 180	$a^2bc^2d^2e^2f^3$	− 1700	$a^2b^2cd^2e^2f^3$	− 60	$a^2c^2d^2f^5$	− 2845	$a^3b^2d^2e^3$
+ 1140	$a^2bc^2d^2ef^2$	+ 480	$a^2b^2cd^2e^2f^2$	− 1420	$a^2c^2def^4$	+ 100	$a^3b^2c^2f^6$
− 870	a^2bc^2def	+ 670	$a^2b^2cdef^2$	+ 25	$a^2c^2e^2f^3$	+ 240	$a^3b^2c^2def^5$
+ 130	$a^2bc^2e^{10}$	− 315	$a^2b^2ce^{10}$	+ 780	$a^2c^2d^2ef^4$	− 540	$a^3b^2c^2e^2f^4$
+ 310	$a^2bcd^2ef^4$	− 685	$a^2b^2d^2ef^4$	+ 5760	$a^2c^2d^2e^2f^3$	+ 220	$a^3b^2c^2d^2f^5$
− 240	$a^2bcd^2e^2f^3$	+ 540	$a^2b^2d^2e^2f^3$	− 2945	$a^2c^2def^2$	− 6000	$a^3b^2c^2d^2ef^4$
− 390	$a^2bcd^2e^2f^2$	+ 1515	$a^2b^2d^2e^2f^2$	+ 1390	$a^2c^2e^2f$	+ 4100	$a^3b^2c^2def^3$
+ 280	$a^2bcd^2e^2f$	− 2080	$a^2b^2d^2ef$	− 7020	$a^2c^2d^2e^2f^3$	+ 1340	$a^3b^2c^2ef^2$
+ 30	$a^2bcd^2e^3$	+ 705	$a^2b^2d^2e^3$	− 180	$a^2c^2d^2e^2f^2$	+11700	$a^3b^2c^2d^2ef^4$
− 180	$a^2bd^2f^4$	+ 110	$a^2b^2c^2df^6$	− 1275	$a^2c^2d^2ef$	−15240	$a^3b^2c^2d^2e^2f^3$
+ 300	$a^2bd^2e^2f^3$	− 195	$a^2b^2c^2e^2f^5$	− 1110	$a^2c^2de^3$	+ 6960	$a^3b^2c^2def$
− 120	$a^2bd^2e^3f^2$	+ 210	$a^2b^2c^2d^2ef^5$	+ 3120	$a^2c^2d^2ef^3$	− 1620	$a^3b^2c^2e^3$
+ 30	$a^2bd^2e^3f$	− 575	$a^2b^2c^2def^4$	+ 3900	$a^2c^2d^2e^2f^2$	− 5760	$a^3b^2c^2d^2f^4$
− 30	$a^2bd^2e^4$	+ 660	$a^2b^2c^2e^2f^3$	+ 1240	$a^2c^2d^2ef$	−16120	$a^3b^2c^2d^2e^2f^3$
+ 15	$a^2c^2df^5$	− 225	$a^2b^2c^2d^2f^3$	+ 3155	$a^2c^2d^2e^3$	+26700	$a^3b^2c^2d^2e^2f^2$
+ 5	$a^2c^2e^2f^5$	+1350	$a^2b^2c^2d^2e^2f^2$	− 515	$a^2c^2d^3f^3$	− 5240	$a^3b^2c^2d^2ef$
− 30	$a^2c^2d^2ef^4$	−1440	$a^2b^2c^2def^3$	− 2920	$a^2c^2d^2e^2f^2$	− 1640	$a^3b^2c^2d^2e^3$
− 270	$a^2c^2def^4$	− 75	$a^2b^2c^2e^3$	− 940	$a^2c^2d^2ef$	+ 6560	$a^3b^2cd^2ef^3$
+ 196	$a^2c^2e^2f^3$	−1965	$a^2b^2c^2d^2ef^4$	− 4300	$a^2c^2d^2e^3$	+ 7240	$a^3b^2cd^2e^2f^2$
+ 225	$a^2c^2d^2e^2f^4$	+6000	$a^2b^2c^2d^2e^2f^3$	+ 675	$a^2c^2d^3ef^2$	−24240	$a^3b^2cd^2ef$
+ 615	$a^2c^2d^2e^2f^3$	−7050	$a^2b^2c^2d^2ef^2$	+ 510	$a^2c^2d^3e^2f$	+11420	$a^3b^2cd^4e^3$
− 660	$a^2c^2de^2f^2$	+3000	$a^2b^2c^2d^2ef$	+ 2940	$a^2c^2d^3e^3$	− 980	$a^3b^2d^7f^3$
+ 45	$a^2c^2e^3f$	+ 265	$a^2b^2c^2de^3$	− 135	$a^2cd^{10}ef$	− 3420	$a^3b^2d^7e^2f^2$
− 120	$a^2c^2d^2ef^4$	+1420	$a^2b^2cd^2f^4$	− 990	$a^2cd^2e^4$	+ 8100	$a^3b^2d^7ef$
− 220	$a^2c^2d^2e^2f^3$	−3810	$a^2b^2cd^2e^2f^3$	+ 135	$a^2d^{11}e^3$	− 3880	$a^3b^2d^8e^3$

No. 29 A (continued).

$-300\ a^5b^2c^2ef^4$	$-800\ a^4c^4d^2e^2f^2$	$+120\ a^3b^4c^4ef^4$	$+153480\ a^3b^3c^4d^3e^6$
$+500\ a^5b^2c^4d^2f^4$	$+22600\ a^4c^4d^4ef$	$-2235\ a^3b^4c^4d^2f^4$	$-26700\ a^3b^3c^4d^7ef^2$
$+3810\ a^5b^2c^4de^2f^4$	$+7240\ a^4c^4de^3$	$-2310\ a^3b^4c^4de^2f^4$	$-41360\ a^3b^3c^4d^4e^2f$
$-3710\ a^5b^2c^4ef^5$	$-1260\ a^4c^4d^3e^2f$	$+10755\ a^3b^4c^4e^2f^3$	$-306900\ a^3b^3c^4d^5e^3$
$-14040\ a^5b^2c^4d^3ef^4$	$-42330\ a^4c^4d^3ef$	$+10625\ a^3b^4c^4d^3ef^4$	$+14360\ a^3b^3c^4d^3f^2$
$+16120\ a^5b^2c^4d^2e^2f^3$	$-34340\ a^4c^4d^2e^3$	$-26700\ a^3b^4c^4d^2e^2f^3$	$-16170\ a^3b^3c^4d^2e^2f$
$-540\ a^5b^2c^4de^3f^2$	$+480\ a^4c^4d^7ef^2$	$+795\ a^3b^4c^4de^4f^2$	$+243000\ a^3b^3c^4d^7e^4$
$+600\ a^5b^2c^4e^4f$	$+48360\ a^4c^4d^4e^2f$	$-10070\ a^3b^4c^4e^3f$	$+2340\ a^3b^3c^4d^{10}ef$
$+7020\ a^5b^2c^4d^5e^4$	$+73828\ a^4c^4d^3e^3$	$+180\ a^3b^4c^3d^7e^4$	$-89550\ a^3b^3c^4d^9e^3$
$-1950\ a^5b^2c^4d^4ef^2$	$+105\ a^4c^4d^8f^2$	$+1950\ a^3b^4c^3d^4e^2f^3$	$+270\ a^3b^3cd^{12}f$
$-17670\ a^5b^2c^4d^3e^2f$	$-30265\ a^4c^4d^7ef$	$+36510\ a^3b^4c^3d^3e^4f$	$+15120\ a^3b^3cd^{11}e^3$
$+4170\ a^5b^2c^4de^5$	$-92290\ a^4c^4d^6e^4$	$+25880\ a^3b^4c^3d^2e^3f^3$	$-810\ a^3b^3d^{13}e$
$+480\ a^5b^2c^3d^4ef^3$	$+9540\ a^4c^4d^{10}ef$	$-32370\ a^3b^4c^3d^2e^2f^2$	$+945\ a^3bc^{10}ef$
$-31040\ a^5b^2c^3d^3e^2f^2$	$+69220\ a^4c^4d^9e^3$	$-12180\ a^3b^4c^3d^2e^4f$	$-675\ a^3bc^9d^3f^4$
$+45180\ a^5b^2c^3d^2e^3f$	$-1215\ a^4c^3d^{12}f$	$-9850\ a^3b^4c^3d^3e^5$	$+7200\ a^3bc^8de^2f^3$
$-3160\ a^5b^2c^3d^3e^4$	$-30510\ a^4c^3d^{11}e^2$	$+195\ a^3b^4cd^5f^3$	$-14115\ a^3bc^8ef^2$
$-140\ a^5b^2c^2d^8f^3$	$+7290\ a^4cd^{13}e$	$-43800\ a^3b^4cd^4e^2f^2$	$-12860\ a^3bc^8d^3ef^3$
$+18000\ a^5b^2c^2d^7e^2f^2$	$-729\ a^4d^{14}$	$+72755\ a^3b^4cd^3e^4f$	$+8220\ a^3bc^8d^2e^2f^2$
$-12180\ a^5b^2c^2d^6e^3f$	$-5\ a^5b^8ef^7$	$-18750\ a^3b^4cd^2e^5$	$+150\ a^3bc^8de^3f$
$-13430\ a^5b^2c^2d^5e^4$	$+15\ a^5b^8def^6$	$+14115\ a^3b^4d^9ef^2$	$+6155\ a^3bc^8e^2$
$-7200\ a^5b^2cd^8ef^2$	$-10\ a^5b^8e^2f^5$	$-23790\ a^3b^4d^8e^3f$	$-480\ a^3bc^7d^4f^3$
$-120\ a^5b^2cd^7e^2f$	$+10\ a^5b^7c^2ef^6$	$+8175\ a^3b^4d^7e^4$	$+26700\ a^3bc^7d^3e^2f^2$
$+9960\ a^5b^2cd^7e^4$	$-120\ a^5b^7cd^3f^6$	$+1320\ a^3b^3c^4df^6$	$+63960\ a^3bc^7d^2e^3f$
$+1890\ a^5b^2d^{11}f^2$	$+420\ a^5b^7cde^2f^5$	$-30\ a^3b^3c^3e^2f^4$	$-6660\ a^3bc^7de^4$
$-540\ a^5b^2d^{10}e^2f$	$-280\ a^5b^7ce^3f^4$	$+540\ a^3b^3c^2d^3ef^4$	$-180600\ a^3bc^6d^2ef$
$-1710\ a^5b^2d^9e^4$	$-240\ a^5b^7d^3ef^5$	$-7240\ a^3b^3c^2de^2f^3$	$-71610\ a^3bc^6d^4e^2$
$-360\ a^5bc^8df^5$	$+210\ a^5b^7d^2e^2f^4$	$-20390\ a^3b^3c^2e^3f^2$	$-4755\ a^3bc^5d^5f^2$
$-240\ a^5bc^8e^2f^4$	$+200\ a^5b^7cdf^6$	$-3900\ a^3b^3cd^4f^4$	$+141240\ a^3bc^5d^4ef^2$
$+5840\ a^5bc^7d^2ef^4$	$-40\ a^5b^7ce^2f^5$	$+31040\ a^3b^3cd^3e^2f^3$	$+219730\ a^3bc^5d^3e^4$
$-6560\ a^5bc^7de^2f^3$	$-1140\ a^5b^6c^3ef^5$	$+32370\ a^3b^3cd^2e^3f^2$	$-45130\ a^3bc^5d^2ef$
$+8460\ a^5bc^7e^3f^2$	$-480\ a^5b^6c^2de^2f^4$	$+38820\ a^3b^3cde^4f$	$-240975\ a^3bc^4d^8e^3$
$-3120\ a^5bc^6d^3f^4$	$+1040\ a^5b^6c^2e^3f^3$	$+9310\ a^3b^3ce^5$	$+5580\ a^3bc^3d^{11}f$
$-480\ a^5bc^6d^2e^2f^3$	$+660\ a^5b^6cd^4f^4$	$-49680\ a^3b^3c^4d^3ef^3$	$+128490\ a^3bc^2d^{10}e^2$
$-25880\ a^5bc^6d^2e^3f^2$	$+1440\ a^5b^6cd^3e^2f^4$	$-91260\ a^3b^3c^4d^2e^2f$	$-34155\ a^3bc^2d^{12}e$
$-1820\ a^5bc^6de^5f$	$-1560\ a^5b^6cd^2e^3f^3$	$-50550\ a^3b^3c^4d^3e^4$	$+3645\ a^3bcd^{14}$
$-3620\ a^5bc^6e^6$	$+960\ a^5b^6d^4ef^4$	$+800\ a^3b^3c^3d^7f^3$	$-1890\ a^2c^{11}e^2f^3$
$+49680\ a^5bc^5d^4e^2f^2$	$-1340\ a^5b^6d^3e^2f^3$	$+81840\ a^3b^3c^3d^4e^2f^2$	$+2700\ a^2c^{10}d^3ef^3$
$+17520\ a^5bc^5d^3ef^3$	$-2440\ a^5b^6d^2e^3f^2$	$+360\ a^3b^3c^3d^3e^3f$	$+7590\ a^2c^{10}de^2f^2$
$+13500\ a^5bc^5d^2e^4$	$+4320\ a^5b^6d^3e^4f$	$+101450\ a^3b^3c^3d^4e^5$	$+8256\ a^2c^{10}e^4f$
$-120\ a^5bc^4d^7f^3$	$-1620\ a^5b^6de^5$	$-8220\ a^3b^3c^2d^5ef^2$	$-105\ a^2c^9d^7f^3$
$-32280\ a^5bc^4d^6e^2f^2$	$-81\ a^5b^5c^5f^6$	$-58080\ a^3b^3c^2d^4e^2f$	$-14360\ a^2c^9d^5e^2f^2$
$-46880\ a^5bc^4d^5e^3f$	$+390\ a^5b^5c^4def^5$	$-34300\ a^3b^3c^2d^3e^3$	$-43605\ a^2c^9d^3e^4f$
$-30040\ a^5bc^4d^4e^4$	$-1515\ a^5b^5c^3e^2f^4$	$-7590\ a^3b^3cd^{10}f^2$	$-12310\ a^2c^9de^6$
$+12860\ a^5bc^4d^3ef^2$	$+980\ a^5b^5c^3d^3f^3$	$+41640\ a^3b^3cd^9e^2f$	$+4755\ a^2c^8d^4ef^2$
$+32000\ a^5bc^4d^2e^3f$	$+7050\ a^5b^5c^3d^2e^2f^4$	$-4650\ a^3b^3cd^8e^4$	$+77790\ a^2c^8d^3e^2f$
$+46160\ a^5bc^4d^4e^5$	$-6000\ a^5b^5c^3de^4f^3$	$-5580\ a^3b^3d^{11}ef$	$+59835\ a^2c^8d^2e^3$
$-2700\ a^5bc^3d^{10}f^2$	$+2440\ a^5b^5c^2e^5f^2$	$+1980\ a^3b^3d^{10}e^2$	$-57060\ a^2c^7d^4ef^2$
$-8820\ a^5bc^3d^9e^2f$	$-15435\ a^5b^5c^2d^4ef^4$	$-270\ a^3b^2c^9e^4$	$-114960\ a^2c^7d^3e^3$
$-34620\ a^5bc^3d^8e^4$	$+15240\ a^5b^5c^2d^3e^3f^3$	$-3150\ a^3b^2c^8def^4$	$+19020\ a^2c^6d^5ef$
$+1080\ a^5bcd^{11}ef$	$-6480\ a^5b^5c^2de^5f$	$+3420\ a^3b^2c^8e^2f^3$	$+109660\ a^2c^6d^4e^2$
$+12060\ a^5bcd^{10}e^2$	$+1215\ a^5b^5c^1e^6$	$+2920\ a^3b^2c^7d^2ef^4$	$-2481\ a^2c^5d^{10}f$
$-1620\ a^5bd^{12}e^3$	$+2945\ a^5b^4cd^2f^4$	$-18000\ a^3b^2c^7d^2e^2f^3$	$-56110\ a^2c^5d^9e^2$
$+81\ a^6c^{10}f^6$	$+540\ a^5b^4cd^1e^2f^3$	$+43800\ a^3b^2c^7de^5f^2$	$+14895\ a^2c^4d^{11}e$
$-990\ a^6c^9def^4$	$-795\ a^5b^4cd^1e^4f^2$	$+5030\ a^3b^2c^6e^6f$	$-1620\ a^2c^3d^{13}$
$+980\ a^6c^8e^2f^3$	$-4180\ a^5b^4cd^3e^2f$	$+32280\ a^3b^2c^6d^4ef^3$	$+1\ ab^{10}f^7$
$+515\ a^6c^6d^3f^4$	$+4185\ a^5b^4cd^2e^3$	$-81840\ a^3b^2c^6d^3e^2f^2$	$+10\ ab^9cef^6$
$+140\ a^6c^6d^2e^2f^3$	$-8460\ a^5b^4d^7ef^4$	$-85800\ a^3b^2c^6d^2e^3f$	$+20\ ab^8d^2f^6$
$-195\ a^6c^6de^4f^2$	$+20390\ a^5b^4d^6e^2f^3$	$-28710\ a^3b^2c^6de^4$	$-130\ ab^8de^2f^5$
$-5575\ a^6c^6e^5f$	$-16194\ a^5b^4d^5e^4f$	$+1260\ a^3b^2c^5d^6f^3$	$+90\ ab^8e^2f^4$
$+120\ a^5c^7d^4ef^3$	$+3765\ a^5b^4d^4e^5$	$+181980\ a^3b^2c^5d^4e^2f$	$-65\ ab^8c^2df^6$

No. 29 A (continued).

−	165	$ab^5c^3e^2f^4$	+	15440	$ab^5cd^7e^2f$	+	44225	$ab^5c^3de^4$	−	370	$b^5c^3d^2f^4$
+	870	$ab^5cd^2ef^4$	+	10350	$ab^5cd^8e^2$	−	141240	$ab^5c^3d^2ef^3$	+	1800	$b^5c^3de^2f^4$
−	670	$ab^5cde^2f^4$	−	8256	$ab^5d^{10}f^3$	+	87000	$ab^5c^3d^2e^2f^3$	+	2845	$b^5c^3e^4f^2$
+	180	$ab^5ce^4f^3$	+	12210	$ab^5d^9e^2f$	−	129000	$ab^5c^3d^2e^3$	+	570	$b^5c^3d^3ef^4$
−	45	$ab^5d^4f^3$	−	7050	$ab^5d^8e^4$	+	57060	$ab^5c^3d^3f^3$	+	1640	$b^5c^3d^2e^2f^3$
+	75	$ab^4d^2e^2f^4$	+	225	$ab^4c^2f^6$	−	5250	$ab^5c^3d^2e^4$	−	4185	$b^5c^3de^2f^2$
−	135	$ab^4d^2e^4f^2$	+	3600	$ab^4c^2def^5$	−	46050	$ab^5c^3d^2ef$	−	4050	$b^5c^3e^3f$
+	30	$ab^4c^4f^4$	−	8100	$ab^4c^2e^2f^3$	+122800		$ab^5c^3d^2e^2$	+	1110	$b^5cd^3f^4$
−	280	$ab^4c^2def^4$	+	940	$ab^4c^2d^3f^4$	+ 10595		$ab^5c^3d^{10}f$	−	4170	$b^5cd^2e^2f^3$
+	2080	$ab^4c^2e^2f^3$	+	12180	$ab^4c^2d^2e^2f^3$	− 88125		$ab^5c^3d^9e^2$	+	6075	$b^5cd^2e^3f$
−	1320	$ab^4c^2d^3f^3$	−	72755	$ab^4c^2de^4f^2$	+ 27300		$ab^5c^3d^{11}e$	+	3620	$b^5d^2ef^3$
−	3000	$ab^4c^2d^2ef^4$	+	4255	$ab^4c^2e^6f$	− 3375		$ab^5c^3d^{12}$	−	9310	$b^5d^2e^2f^2$
+	4880	$ab^4c^2de^2f^3$	+	46880	$ab^4c^2d^3ef^3$	− 1080		$abc^{11}def^3$	+	8550	b^5d^3ef
−	4320	$ab^4c^2e^3f^2$	−	360	$ab^4c^2d^5e^2f^2$	+ 5580		$abc^{11}ef^4$	−	3375	$b^5d^3e^2$
+	2760	$ab^4cd^4ef^4$	+148890		$ab^4c^2d^5ef$	− 9540		$abc^{10}d^2f^3$	+	210	$b^5c^4df^4$
−	6960	$ab^4cd^3e^2f^3$	+ 38950		$ab^4c^2de^7$	− 2340		$abc^{10}d^2e^2f^2$	−	615	$b^5c^4ef^4$
+	6480	$ab^4cd^2e^2f^3$	+ 42330		$ab^4c^2d^4e^2f^2$	+ 20610		$abc^{10}def$	−	1285	$b^5c^3d^3ef^4$
−	1390	$ab^4d^3f^4$	−181980		$ab^4c^2d^4e^3f^2$	− 4350		$abc^{10}e^4$	−	11420	$b^5c^3de^2f^3$
−	600	$ab^4d^4e^2f^3$	−220125		$ab^4c^2d^3e^4$	+ 45130		$abc^9d^3ef^3$	−	3765	$b^5c^3e^3f^2$
+	10070	$ab^4d^4e^3f^2$	− 63960		$ab^4c^2d^2ef^3$	− 92200		$abc^9d^2e^2f$	−	3155	$b^5c^2d^4f^4$
−	12600	$ab^4d^3e^4f$	+181600		$ab^4c^2d^2e^2f$	− 25050		$abc^9d^2e^4$	+	3160	$b^5c^2d^3e^2f^3$
+	4050	$ab^4d^2e^6$	+159000		$ab^4c^2d^3e^4$	− 19020		$abc^8d^3f^3$	+	9850	$b^5c^2d^2e^2f^2$
−	30	$ab^4c^6ef^4$	+ 43605		$ab^4c^2d^3ef^2$	+ 46050		$abc^8d^2e^2f$	+	19800	$b^5c^2def^3$
+	1995	$ab^4c^4d^2f^4$	− 62025		$ab^4c^2d^2e^2f^2$	+138750		$abc^8d^2e^4$	+	3375	$b^5c^2e^6$
−	1795	$ab^4c^4def^4$	− 92500		$ab^4c^2d^7e^4$	−178200		$abc^7d^3e^3$	−	13500	$b^5c^2d^3ef^3$
−	9875	$ab^4c^4e^2f^3$	− 20610		$ab^4cd^{10}ef$	− 1650		abc^6d^3f	+	50550	$b^5c^2d^4e^2f^2$
+	3220	$ab^4c^4d^3ef^4$	+ 41250		$ab^4cd^9e^2$	+103950		$abc^6d^2e^2$	−	62100	$b^5c^2d^3ef$
+	5240	$ab^4c^4d^2e^2f^3$	+ 5445		$ab^4d^{12}f$	− 30250		$abc^6d^{10}e$	−	7240	$b^5cd^7e^2f^2$
+	4180	$ab^4c^4de^2f^2$	− 6525		$ab^4d^{11}e^2$	+ 3600		abc^4d^{12}	+	28710	$b^5cd^4e^2f^2$
+	12600	$ab^4c^4e^3f$	− 900		$ab^3c^6ef^4$	+ 1215		$ac^{13}d^2f^3$	−	38950	$b^5cd^3e^4f$
+	1275	$ab^4c^3d^3f^4$	− 510		$ab^3c^5d^3f^4$	− 270		$ac^{13}de^2f^2$	+	25875	$b^5cd^4e^6$
+	17670	$ab^4c^3d^2e^2f^3$	+ 120		$ab^3c^5de^2f^3$	− 5445		$ac^{12}e^4f$	−	6155	$b^5d^6ef^3$
−	36510	$ab^4c^3d^3e^2f^2$	+ 23790		$ab^3c^5e^4f^2$	− 5580		$ac^{11}d^2ef^2$	+125000		$b^5d^5e^2f$
−	6075	$ab^4c^3de^6$	− 32000		$ab^3c^4d^5ef^3$	+ 17520		$ac^{11}d^2e^3f$	−	7375	$b^5d^6e^3$
+	1820	$ab^4cd^6ef^3$	+ 58080		$ab^3c^4d^4e^2f^2$	+ 8700		$ac^{11}de^5$	−	45	$b^5c^7f^4$
−	38820	$ab^4cd^5e^2f^2$	− 15440		$ab^3c^4d^6ef$	+ 2481		$ac^{10}d^3f^3$	+	615	$b^5c^6def^4$
+	66650	$ab^4cd^4e^4f$	− 12500		$ab^3c^4e^8$	− 10595		$ac^{10}d^2e^2f$	+	3880	$b^5c^6e^2f^3$
−	19800	$ab^4cd^3e^6$	− 48360		$ab^3c^3d^7f^3$	− 31150		$ac^{10}de^4$	+	4300	$b^5c^5d^2f^4$
+	5575	$ab^4d^7f^3$	+ 41360		$ab^3c^3d^6e^2f^2$	+ 1650		ac^9d^3ef	+	13430	$b^5c^5d^2e^2f^3$
−	5030	$ab^4d^6e^2f^2$	−181600		$ab^3c^3d^5e^4f$	+ 37950		$ac^9d^2e^3$	+	18750	$b^5c^5de^4f^2$
−	4255	ab^4d^5ef	− 18400		$ab^3c^3d^4e^6$	− 22275		$ac^8d^7e^2$	−	2175	b^5c^4ef
+	2175	$ab^4d^5e^3$	+180600		$ab^3c^3d^3ef^5$	+ 6600		ac^7d^8e	+	30040	$b^5c^4d^5ef^3$
−	1110	$ab^4c^6df^3$	+289800		$ab^3c^3d^4e^4$	− 800		ac^6d^{11}	−101450		$b^5c^4d^4e^2f^2$
+	870	$ab^4c^6e^2f^4$	− 77790		$ab^3c^3d^2f^3$	− 5		$b^{11}ef^4$	−	1850	$b^5c^4d^3ef$
−	5550	$ab^4c^5d^2ef^4$	− 87000		$ab^3c^3d^2ef$	+ 10		$b^{10}cdf^4$	−	25875	$b^5c^4de^2$
+	24240	$ab^4c^5def^3$	−318500		$ab^3c^3d^3e^2$	+ 75		$b^{10}ce^2f^3$	+	34340	$b^5c^3d^2f^3$
+	16194	$ab^4c^5e^2f^2$	+ 92200		$ab^3c^3d^2ef$	− 130		$b^{10}d^2ef^3$	−153480		$b^5c^3d^2e^2f^2$
−	1240	$ab^4c^4d^4f^4$	+179500		$ab^3c^3d^2e^3$	+ 310		$b^{10}de^2f^4$	+220125		$b^5c^3d^2e^4f$
−	45180	$ab^4c^4d^3e^2f^3$	− 17520		$ab^3c^2d^{11}f$	− 216		$b^{10}e^4f^3$	+	6660	$b^5c^3d^3ef^2$
+	12180	$ab^4c^4d^2e^4f^2$	− 69000		$ab^3c^2d^{10}e^2$	− 5		$b^9e^7f^3$	+	18400	$b^5c^3d^2e^2f$
−	66650	$ab^4c^4def^2$	+ 15300		$ab^3cd^{12}e$	− 30		$b^8c^2def^5$	−	73375	$b^5c^3d^3e^3$
−	8550	$ab^4c^4e^8$	− 1350		ab^3d^{14}	− 705		$b^8c^2e^2f^4$	+	12310	$b^5cd^5f^2$
−	17520	$ab^3c^6d^2ef^3$	+ 135		$ab^2c^{10}df^4$	+ 260		$b^8cd^4f^5$	−	44225	$b^5cd^4e^2f$
+	91260	$ab^3c^6d^4e^2f^2$	+ 540		$ab^2c^{10}e^2f^3$	− 265		$b^8cd^3e^2f^4$	+	42500	$b^5cd^7e^4$
+	62100	$ab^3c^6d^3e^4$	+ 8820		$ab^2c^9d^2ef^3$	− 990		$b^8cde^4f^3$	+	4350	$b^5d^{13}ef$
−	22600	$ab^3c^5d^7f^3$	− 41640		$ab^2c^9de^2f^2$	+ 1620		$b^8ce^6f^2$	−	5125	$b^5d^9e^2$
+	85800	$ab^3c^5d^4e^2f^2$	− 12210		$ab^2c^9e^4f$	− 555		$b^7d^2ef^4$	−	45	$b^5c^6ef^4$
−148890		$ab^3c^5d^3e^4f$	+ 30265		$ab^2c^8d^3f^3$	+ 1620		$b^7d^2e^2f^3$	−	2940	$b^5c^5d^2f^4$
+	1850	$ab^3c^5d^4e^6$	+ 16170		$ab^2c^8d^2e^2f^2$	− 1215		$b^7d^2e^4f^2$	−	9960	$b^5c^5de^2f^3$
−	150	$ab^3cd^8ef^3$	+ 62025		$ab^2c^8d^2e^4f$	+ 30		$b^6c^4ef^5$	−	8175	$b^5c^4e^2f^3$

No. 29 A (continued).

− 46160 $b^5c^6d^3ef^2$	−243000 $b^5c^7d^3e^2f^2$	+ 80125 $b^5c^8d^3e^5$	+ 500 $b^5c^9d^{11}$
+ 34300 $b^5c^6d^2e^2f$	+ 92500 $b^5c^7d^2e^4f$	−109660 $b^5c^7d^6f^2$	− 7290 $bc^{13}df^3$
− 10350 $b^5c^6de^3f$	− 42500 $b^5c^7de^6$	−122800 $b^5c^7d^5e^2f$	+ 810 $bc^{13}e^2f^2$
+ 7375 $b^5c^6e^7$	−219730 $b^5c^6d^4e^2f^2$	+ 1250 $b^5c^7d^4e^4$	+ 34155 $bc^{12}d^2ef^2$
− 73828 $b^5c^6d^4f^3$	+318500 $b^5c^6d^4e^4f$	+178200 $b^5c^6d^7ef$	− 15300 $bc^{12}de^2f$
+306900 $b^5c^6d^3e^2f^2$	− 80500 $b^5c^6d^3e^6$	− 37950 $b^5c^6d^9f$	+ 1125 $bc^{12}e^4$
−159000 $b^5c^6d^3e^4f$	+114960 $b^5c^6d^7f^2$	− 37125 $b^5c^6d^8e^3$	− 14895 $bc^{11}d^4f^2$
+ 73375 $b^5c^6d^3e^6$	+ 5250 $b^5c^6d^5ef$	+ 17875 $b^5c^6d^{10}e$	− 27300 $bc^{11}d^3e^2f$
+ 71610 $b^5c^6d^2ef^2$	−138750 $b^5c^6d^5ef$	− 2125 $b^5c^6d^{12}$	+ 18750 $bc^{11}d^2e^4$
−289800 $b^5c^6d^2e^3f$	− 1250 $b^5c^6d^7e^3$	+ 1620 $b^5c^{13}ef^2$	+ 30250 $bc^{10}d^4ef$
− 59835 $b^5c^6d^2f^3$	+ 31150 $b^5c^6d^{10}f$	+ 30510 $b^5c^{11}d^2f^3$	− 17875 $bc^{10}d^4e^3$
+129000 $b^5c^6d^2e^5f$	+ 40000 $b^5c^6d^4e^3$	− 15120 $b^5c^{11}def^4$	− 6600 bc^9d^7f
+ 80500 $b^5c^6d^2e^7$	− 18750 $b^5c^6d^{11}e$	+ 6525 $b^5c^{11}e^4f$	+ 4125 $bc^9d^6e^3$
+ 25050 $b^5c^6d^3ef$	+ 2250 b^5cd^{13}	−128490 $b^5c^{10}d^3ef^2$	+ 729 $c^{15}f^3$
− 80125 $b^5c^6d^3e^3$	− 135 $b^5c^{11}e^4$	+ 69000 $b^5c^{10}d^2e^2f$	− 3645 $c^{14}def^2$
− 8700 $b^5cd^{11}f$	− 12060 $b^5c^{10}def^3$	− 19875 $b^5c^{10}de^5$	+ 1350 $c^{14}e^2f$
+ 19875 $b^5cd^{10}e^2$	− 1980 $b^5c^{10}e^2f^2$	+ 56110 $b^5c^9d^2f^2$	+ 1620 $c^{13}d^3f^2$
− 1125 $b^5d^{12}e$	− 69220 $b^5c^9d^2f^3$	+ 88125 $b^5c^9d^4e^2f$	+ 3375 $c^{13}d^2e^2f$
+ 990 $b^5c^6df^4$	+ 89550 $b^5c^9d^2e^2f^2$	− 40000 $b^5c^9d^2e^4$	− 2250 $c^{13}de^6$
+ 1710 $b^5c^6e^2f^3$	− 41250 $b^5c^9de^4f$	−103950 $b^5c^8d^3ef$	− 3600 $c^{12}d^4ef$
+ 34620 $b^5c^6d^2ef^3$	+ 5125 $b^5c^9e^6$	+ 37125 $b^5c^8d^4e^3$	+ 2125 $c^{12}d^3e^3$
+ 4650 $b^5c^6de^2f^2$	+240975 $b^5c^8d^4ef^2$	+ 22275 $b^5c^7d^5f$	+ 800 $c^{11}d^4f$
+ 7050 $b^5c^6e^4f$	−179500 $b^5c^8d^3e^2f$	− 4125 $b^5c^8d^3e$	− 500 $c^{11}d^4e^2$.
+ 92290 $b^5c^6d^4f^2$			

Mr. SALMON has also remarked to me, that in the Table No. 50 of the cubinvariant of a binary dodecadic *, the coefficients are altogether erroneous. There was, in fact, a fundamental error in the original calculation; instead of repeating it, I have, with a view to the deduction therefrom of the cubinvariant (see Fourth Memoir, No. 78), first calculated the dodecadic quadricovariant, the value of which is given in the following Table:—

No. 49 A.

+ 1 ag	+ 6 ah	+ 15 ai	+ 20 aj	+ 15 ak	+ 6 al	+ 1 am
− 6 bf	−30 bg	− 54 bh	− 30 bi	+ 30 bj	+ 54 bk	+ 30 bl
+15 ce	+54 cf	+ 24 cg	−150 ch	−270 ci	− 150 cj	+ 24 ck
−10 d^2	−30 de	+150 df	+430 dg	+270 dh	− 270 di	−430 dj
		−135 e^3	−270 ef	+495 eg	+1080 eh	+495 ei
				−540 f^3	− 720 fg	+720 fh
						−840 g^2

($\Sigma(x, y)^{12}$.

+ 6 bm	+ 15 cm	+ 20 dm	+ 15 em	+ 6 fm	+ 1 gm
+ 54 cl	+ 30 dl	− 30 el	− 54 fl	−30 gl	− 6 hl
− 150 dk	−270 ek	−150 fk	+ 24 gk	+54 hk	+15 ik
− 270 ej	+270 fj	+430 gj	+150 hj	−30 ij	−10 j^2
+1080 fi	+495 gi	−270 hi	−135 i^3		
− 720 gh	−540 h^2				

* Third Memoir, Philosophical Transactions, t. cxlvi. (1856) p. 635.

It is now very easy to obtain the cubinvariant, which is

No. 50 bis.

$+1$	agm	-54	cfl	$+270$	dhi
-6	ahl	$+24$	cgk	-135	e^2k
$+15$	aik	$+150$	chj	$+270$	efj
-10	aj^2	-135	ci^2	$+495$	egi
-6	bfm	-10	d^3m	-540	eh^2
$+30$	bgl	$+30$	del	-540	f^2i
-54	bhk	$+150$	dfk	$+720$	fgh
$+30$	bij	-430	dgj	-280	g^3
$+15$	cem				

XXIV. *On the Tangential of a Cubic.* By Arthur Cayley, *Esq.*, *F.R.S.*

Received February 11,—Read March 18, 1858.

In my "Memoir on Curves of the Third Order*," I had occasion to consider a derivative which may be termed the "tangential" of a cubic, viz. the tangent at the point (x, y, z) of the cubic curve $(*\between x, y, z)^3=0$ meets the curve in a point (ξ, η, ζ), which is the tangential of the first-mentioned point; and I showed that when the cubic is represented in the canonical form $x^3+y^3+z^3+6lxyz=0$, the coordinates of the tangential may be taken to be $x(y^3-z^3):y(z^3-x^3):z(x^3-y^3)$. The method given for obtaining the tangential may be applied to the general form $(a, b, c, f, g, h, i, j, k, l\between x, y, z)^3$: it seems desirable, in reference to the theory of cubic forms, to give the expression of the tangential for the general form†; and this is what I propose to do, merely indicating the steps of the calculation, which was performed for me by Mr. Creedy.

The cubic form is

$$(a, b, c, f, g, h, i, j, k, l\between x, y, z)^3,$$

which means

$$ax^3+by^3+cz^3+3fy^2z+3gz^2x+3hx^2y+3iyz^2+3jzx^2+3hxy^2+6lxyz;$$

and the expression for ξ is obtained from the equation

$$\begin{aligned} x^2\xi=&(b, f, i, c\between(j, f, c, i, g, l\between x, y, z)^2, -(h, b, i, f, l, k\between x, y, z)^2)^3\\ &-(a, b, c, f, g, h, i, j, k, l\between x, y, z)^2(\mathfrak{C}x+\mathfrak{B}), \end{aligned}$$

where the second line is in fact equal to zero, on account of the first factor, which vanishes. And $\mathfrak{C}$, $\mathfrak{B}$ denote respectively quadric and cubic functions of (y, z), which are to be determined so as to make the right-hand side divisible by x^2; the resulting value of ξ may be modified by the adjunction of the evanescent term

$$(2x+hy+gz)(a, b, c, f, g, h, i, j, k, l\between x, y, z)^2,$$

where a, g, h are arbitrary coefficients; but as it is not obvious how these coefficients should be determined in order to present the result in the most simple form, I have given the result in the form in which it was obtained without the adjunction of any such term.

Write for shortness

$$\begin{aligned} P&=(k, l \between y, z),\\ Q&=(b, f, i \between y, z)^2, \end{aligned}$$

* Philosophical Transactions, vol. cxlvii. 1857.

† At the time when the present paper was written, I was not aware of Mr. Salmon's theorem (Higher Plane Curves, p. 156), that the tangential of a point of the cubic is the intersection of the tangent of the cubic with the first or line polar of the point with respect to the Hessian; a theorem, which at the same time that it affords the easiest mode of calculation, renders the actual calculation of the coordinates of the tangential less important. Added 7th October, 1858.—A. C.

$$\begin{aligned}
\mathrm{R} &= (l,\ g,\ \quad \between y, z)\,,\\
\mathrm{S} &= (f,\ i,\ c\ \between y, z)^2,\\
\mathrm{B} &= (h,\ j\ \quad \between y, z)\,,\\
\mathrm{C} &= (k,\ l,\ g\ \between y, z)^2,\\
\mathrm{D} &= (b\,,\ f,\ i,\ c \between y, z)^3,
\end{aligned}$$

so that

$$\begin{aligned}
(h, b, i, f, l, k \quad \between x, y, z)^3 &= (h\,,\ \mathrm{P},\ \mathrm{Q}\quad \between x, 1)^2,\\
(j, f, c, i, g, l \quad \between x, y, z)^3 &= (j\,,\ \mathrm{R},\ \mathrm{S}\quad \between x, 1)^2,\\
(a, b, c, f, g, h, i, j, k, l \between x, y, z)^3 &= (a\,,\ \mathrm{B},\ \mathrm{C},\ \mathrm{D} \between x, 1)^3.\\
\mathfrak{C}x+\mathfrak{B} \quad &= (\mathfrak{C}, \mathfrak{B}\quad \between x, 1),
\end{aligned}$$

and then for greater convenience writing $(h,\ 2\mathrm{P},\ \mathrm{Q} \between x, 1)^2$, &c. for $(h,\ \mathrm{P},\ \mathrm{Q} \between x, 1)^2$, &c., and omitting the $(x, 1)^2$, &c. and the arrow-heads, or representing the functions simply by $(h,\ 2\mathrm{P},\ \mathrm{Q})$, &c., we have

$$\begin{aligned}
x^3\xi = \ & b(j,\ 2\mathrm{R},\ \mathrm{S}\quad)^3\\
& -3f(j,\ 2\mathrm{R},\ \mathrm{S}\quad)^2.(h\,,\ 2\mathrm{P},\ \mathrm{Q})\\
& +3i(j,\ 2\mathrm{R},\ \mathrm{S}\quad).(h\,,\ 2\mathrm{P},\ \mathrm{Q})^2\\
& -\ c\qquad\qquad\qquad\qquad .(h\,,\ 2\mathrm{P},\ \mathrm{Q})^3\\
& -\ (a,\ 3\mathrm{B},\ 3\mathrm{C},\ \mathrm{D}).(\mathfrak{C},\ \mathfrak{B}\quad),
\end{aligned}$$

which can be developed in terms of the quantities which enter into it. The conditions, in order that the coefficients of x, x^2 may vanish, are thus seen to be

$$\mathrm{D}\mathfrak{B} = b\mathrm{S}^3 - 3f\mathrm{S}^2\mathrm{Q} + 3i\mathrm{S}\mathrm{Q}^2 - c\mathrm{Q}^3,$$

$$\mathrm{D}\mathfrak{C} - 3\mathrm{C}\mathfrak{B} = b(6\mathrm{R}\mathrm{S}^2) - 3f(2\mathrm{S}^2\mathrm{P} + 4\mathrm{R}\mathrm{S}\mathrm{Q}) + 3i(2\mathrm{R}\mathrm{Q}^2 + 4\mathrm{S}\mathrm{P}\mathrm{Q}) - c6\mathrm{P}\mathrm{Q}^2,$$

and from these we obtain

$$\mathfrak{C} = \left(\begin{array}{|c|c|c|}
-3\ bek & +6\ big & +3\ bcg\\
+6\ bil & -6\ cfk & -6\ cfl\\
+3\ fik & -6\ f^2g & -3\ fgi\\
-6\ f^2l & +6\ i^2k & +6\ i^2l
\end{array}\right) \between y, z)^2$$

$$\mathfrak{B} = \left(\begin{array}{|c|c|c|c|}
-1\ b^3c & -3\ bcf & +3\ bci & +1\ bc^2\\
+3\ bfi & +6\ bi^2 & -6\ cf^2 & -3\ cfi\\
-2\ f^3 & -3\ f^2i & +3\ fi^2 & +2\ i^3
\end{array}\right) \between y, z)^3$$

and substituting these values, the right-hand side of the equation divides by x^2, and throwing out this factor we have the value of ξ; and the values of η, ζ may be thence deduced by a mere interchange of letters. The value for ξ is

x^4	x^3y	x^3z	x^2y^2	x^2yz	x^2z^2	xy^3	xy^2z	xyz^2	xz^3	y^4	y^3z	y^2z^2	yz^3	z^4
$+1\ bj^3$	$+6\ bj^2l$	$+6\ bjj^2$	$+3\ abck$	$-6\ abgi$	$-3\ abcg$	$+1\ ab^3c$	$+3\ abcf$	$-3\ abci$	$-1\ abc^3$	$+3\ b^2ij$	$+3\ b^2cj$	$+9\ bcfj$	$-3\ bc^2h$	$+3\ bcg^2$
$-1\ ck^3$	$-6\ ck^2k$	$-6\ ck^2l$	$-6\ abil$	$+6\ acfk$	$+6\ acfl$	$-3\ abfi$	$-6\ abf^2$	$+6\ acf^2$	$+3\ acfi$	$-3\ bck^2$	$-3\ bcfh$	$-9\ bchi$	$+6\ bcgl$	$-3\ c^2fh$
$-3\ fhj^2$	$-12\ fhjl$	$-12\ fghj$	$+6\ af^2l$	$+6\ af^2g$	$+3\ afgi$	$+2\ af^3$	$+3\ af^2i$	$-3\ afi^2$	$-2\ ai^3$	$-3\ bf^2j$	$-3\ bckl$	$+18\ bgil$	$+3\ bcij$	$-6\ cfgl$
$+3\ k^2ij$	$-6\ fj^2k$	$-6\ fj^2l$	$-3\ afik$	$-6\ ai^2k$	$-6\ ai^2l$	$-3\ bchk$	$-12\ bchl$	$-9\ bcgh$	$+3\ bcgj$	$-3\ bfhi$	$+3\ bfij$	$-18\ cfkl$	$+6\ bg^2i$	$+3\ cfij$
	$+6\ k^2il$	$+6\ gk^2i$	$-3\ bck^3$	$+24\ bgjl$	$+3\ bcj^2$	$-6\ bhil$	$+9\ bcjk$	$+12\ bcjl$	$+8\ bg^3$	$+6\ bikl$	$+3\ bgik$	$-18\ f^2gl$	$+6\ cf^2j$	$+3\ chi^2$
	$+12\ hijk$	$+12\ hijl$	$+6\ bhij$	$+6\ bij^2$	$+12\ bg^2j$	$+12\ bijk$	$-6\ bghi$	$+24\ bg^2l$	$-12\ cfgh$	$+3\ f^3h$	$-6\ bhi^2$	$-9\ f^2ij$	$-6\ cfgk$	$-3\ fg^2i$
			$+12\ bjl^2$	$-6\ cfk^2$	$-6\ cfhj$	$+8\ bl^3$	$+24\ bgl^2$	$+6\ bgij$	$+3\ cfjl$	$-6\ f^2kl$	$+12\ bil^2$	$+9\ fhi^2$	$-3\ cfhi$	$+6\ gi^2l$
			$-12\ chk^2$	$-24\ chkl$	$-24\ fjl^2$	$-8\ ck^3$	$+18\ bijl$	$-18\ cfhl$	$-8\ cl^3$	$+3\ fik^2$	$-6\ cfk^2$	$+18\ i^2kl$	$-12\ cfl^2$	$-3\ i^3j$
			$-6\ f^2hj$	$-6\ f^2j^2$	$-12\ fg^2h$	$+6\ f^3kl$	$-6\ cfhk$	$+6\ cfjk$	$-24\ fg^2l$		$-6\ f^2j$		$-6\ f^2g^2$	
			$-3\ fk^2i$	$-24\ fghl$	$-24\ fgjl$	$-12\ f^2jk$	$-24\ ck^2l$	$-24\ ckl^2$	$-3\ fgij$		$-6\ f^2gk$		$-6\ fgil$	
			$-12\ fkl^2$	$-24\ fgjk$	$-3\ fij^2$	$+3\ fhik$	$+6\ f^2gh$	$-6\ f^2gj$	$+12\ ghi^2$		$+9\ f^2hi$		$-9\ fi^2j$	
			$-24\ fkl$	$-24\ fjl^2$	$+24\ ghil$	$-24\ fkl^2$	$-18\ f^2jl$	$-24\ fg^2k$	$+24\ gil^2$		$-12\ f^2l^2$		$+6\ gi^2k$	
			$+24\ hikl$	$+24\ ghik$	$+6\ hi^2j$	$+24\ ik^2l$	$-48\ fghl$	$+9\ fghi$	$-6\ i^2jl$		$+6\ fikl$		$+6\ hi^2$	
			$+12\ ijk^2$	$+6\ k^2i^2$	$+12\ ijl^2$		$+12\ fhil$	$-48\ fgl^2$			$+6\ i^2k^2$		$+12\ i^2l^2$	
				$+24\ hil^2$			$-9\ fijk$	$-12\ fijl$						
				$+24\ ijkl$			$-24\ fl^3$	$+48\ gikl$						
							$+24\ gik^2$	$+18\ hi^2l$						
							$+6\ k^3k$	$-6\ i^2jk$						
							$+48\ ikl^2$	$+24\ il^3$						

And it is not necessary to write down the corresponding values for η, ζ.

XXV. *Astronomical Experiment on the Peak of Teneriffe, carried out under the sanction of the Lords Commissioners of the Admiralty.* By Professor C. Piazzi Smyth. *Communicated by* G. B. Airy, *Esq., Astronomer Royal.*

Received June 2,—Read June 18, 1857.

CHAPTER I.

INTRODUCTORY.

(1.) *Origin and Objects.*

The principal object of the experiment on Teneriffe in the summer of 1856, was to ascertain how much astronomical observation can be benefited, by eliminating the lower third or fourth part of the atmosphere. That the amount of such improvement would be large and form a desirable boon to practical astronomy, appears to have been expected by Sir Isaac Newton; for in his 'Optics' he expressly says, "They (telescopes) cannot be so formed as to take away that confusion of rays which arises from the tremors of the atmosphere. The only remedy is a most serene and quiet air, such as may perhaps be found on the tops of the highest mountains above the grosser clouds."

After having enjoyed some slight practical experience of the method so recommended, during the remeasurement of La Caille's Southern Arc of the Meridian under Mr. Maclear, its further prosecution was brought prominently to my attention by the peculiar position of the Edinburgh Observatory. Accordingly, in November 1852, I had the honour of presenting to the Board of Visitors, under the Presidency of the Right Hon. Lord Rutherfurd, a scheme for realizing Newton's idea through means of a summer expedition to the Peak of Teneriffe; where there appeared a hope that telescopes might be elevated more than 10,000 feet above the level of the sea, with greater facilities of every sort, than on any other known mountain. The same project was also brought before Section A. of the British Association, three years later.

In the autumn of 1855, a copy of the Edinburgh Observatory Report reached the hands of R. Stephenson, Esq., M.P.; and he found its indications to agree so well with his own experience in early life on South American Cordilleras, that, though we were entirely unacquainted, he very kindly sent me, through a mutual friend, an offer of a passage to Teneriffe in his yacht 'Titania.' Circumstances, however, prevented my profiting by his kindness on that occasion.

Finally, in the spring of 1856, the Astronomer Royal, G. B. Airy, Esq., having himself engaged in some special astronomical inquiries, where success was rendered impossible by interference of the atmosphere; and having become convinced of the per-

fect practicability of making an experiment on the Peak of Teneriffe,—laid a statement to that effect before the First Lord of the Admiralty, the Right Honourable Sir CHARLES WOOD.

That Minister instantly saw the importance of the proposition, and entering most warmly and liberally into it, at once agreed to furnish such funds as would enable me to proceed immediately to Teneriffe; and, with due permission from the Spanish authorities, make trial of the capabilities of the mountain. The first estimate amounted to £300; but so noble a view did the Admiralty take of the matter, that they inquired, through their Hydrographer (Captain WASHINGTON), if £300 was not too small a sum for the efficient performance of the service. Having in the meantime received good reasons from Mr. AIRY for taking out a larger telescope than I had at first contemplated, I sent in a second estimate for £500, and it was immediately authorized.

The spring being now well advanced (May the 2nd), there was but short time to prepare; and it is here proper again to express my obligations to the Admiralty, who left me unfettered by any instructions, except the very reasonable one of not exceeding the grant. The preparations therefore went on rapidly in May and June.

Meanwhile the Admiralty wrote to the Royal Society, the Royal Astronomical Society, the British Association, Sir JOHN HERSCHEL, Mr. AIRY, and the Director of the Ordnance Survey, informing them of the authorization, and inquiring if they had any suggestions to offer.

These several parties highly approved of the measure, but sent in propositions for so much additional work, that the whole scale of the mission, its time for preparation, and for execution, its materials, men, and money, would have had to be greatly extended to include them all. Many reasons, however, dictated the propriety of keeping to the original idea, of making the experiment for the summer of 1856 a tentative one merely.

A capability nevertheless of attending to many of the very important suggestions thus made, and without exceeding the Admiralty allowance, was acquired before long through the liberal loans made by private individuals. The number and value of these are so interesting a proof of the estimation in which the undertaking, as an attempt to solve an important problem in practical astronomy, was viewed by the scientific men of Great Britain, that they may well be entered here.

(1.) Actinometer, Magnetometer, two Radiation thermometers, Electrometer, Spectrum apparatus, and Polarimeter. By G. B. AIRY, Astronomer Royal. (2.) Equatorial instrument; the telescope 11 feet in focal length, and 7¼ inches aperture with clock motion. By H. L. PATTINSON, Esq., of Newcastle-on-Tyne. (3.) A Quartz train for spectrum observations. By Professor G. G. STOKES. (4.) Mountain Barometer, and six thermometers. By Dr. LEE of Hartwell. (5.) Mountain Barometer, and four thermometers. By J. ADIE, Esq., of Edinburgh. (6.) A Thermo-multiplier. By J. P. GASSIOT, Esq., F.R.S. (7.) Four barometers, twelve thermometers and hydrometers compared at the Kew Observatory, with blank books and maps. By Admiral FITZROY on the part of the Board of Trade. (8.) Four Chronometers. By the Hydro-

grapher to the Admiralty, Captain WASHINGTON. (9.) Double Sextant. By Admiral BEECHEY. (10.) Polarization apparatus. By the Rev. BADEN POWELL. (11.) Plane speculum and apparatus to facilitate the observation of red prominences round the sun. By J. NASMYTH, C.E. (12.) Eyepieces and adaptations to Equatorial. By T. COOKE, Esq., of York. (13.) Lastly, by ROBERT STEPHENSON, Esq., M.P., was made the loan of his yacht 'Titania' of 140 tons, and with a crew of sixteen men, for the voyage out and home, and during the whole period of the experiment.

In addition to the above instruments, I took from the Edinburgh Observatory the 5-foot equatorial, presented some years since by the late Rev. R. SHEEPSHANKS; and received much kind assistance from Admirals MANNERS and W. H. SMYTH, Sir DAVID BREWSTER, Mr. WELSH of Kew, and J. J. FORRESTER, Esq.; while in their official capacities, Lord CLARENDON, J. MURRAY, the British Consul in Santa Cruz, and A. GOODALL, acting Vice-Consul in Orotava, rendered important services; and I have to mention with thanks my obligations to the Spanish authorities, to L. HAMILTON, Esq., C. SMITH, Esq., Don FRANCISCO AGUILAR, Don MARTIN RODRIGUEZ, Mr. ANDREW CARPENTER, and Herr KREITZ, all of Teneriffe; as well as to the Brazilian Steam Packet Company.

(2.) *Instructions and Suggestions.*

The leading object given to me was, as already stated, to ascertain how much astronomical observation can be benefited by raising telescopes high into the air, and so enabling an observer to look at the celestial bodies through a less depth of atmosphere than they could from any of the ordinary observatories, established as they are, at or near the level of the sea.

If we could rise high enough above the clouds, not only should we at once have clear in place of cloudy skies,—no mean advantage in itself, as enabling us to increase the number of observations,—but their quality, a matter of far higher importance, would be advanced at the same time. For in proportion as the atmosphere itself is overpassed, so are the irregularities in its action on rays of light passing through it; and these irregularities are precisely what form the chief bar to accuracy of instrumental measure, and to certainty of telescopic vision.

On the other hand exist the drawbacks, that on a high mountain it may be difficult to drag up the largest class of telescope, and impossible to build a large observatory; and though the air be thin and transparent, it may be in such a state of motion as to be prejudicial to the steadiness of instruments; or again, the mountain top may be always enveloped in a local cloud. The exact value of these objections was only to be found by actual trial; and that, if they should be overcome, a new gateway would be opened up in the paths of science, not astronomical only, but of many allied subjects, may be gathered from the very important mass of suggestions sent into the Admiralty by their several referees, as below. They show indeed, what might be expected from a good mountain station, well worked for a series of years, rather than what a preliminary experimental trial on a small scale would be able to accomplish in a few weeks.

I.—*Letter from* G. B. AIRY, *Astronomer Royal, to the Secretary of the Admiralty, dated 13th May*, 1856.

"SIR,—I have the honour to acknowledge your letter of the 2nd instant, acquainting me with the sanction of the Lords Commissioners of the Admiralty to a grant of £500 to Professor PIAZZI SMYTH for defraying the expenses of an astronomical visit to the Peak of Teneriffe, and requesting me to communicate any suggestions for the due carrying out of this project, which may occur to me.

"2. In reply, I would first submit to My Lords, that though it is desirable that some document of the character of Instructions should be issued, as indicating their Lordships' general understanding of the grounds on which they have sanctioned this appropriation of public money, yet on the other hand it is most desirable that the several heads should be so lightly stated, as to leave Professor SMYTH in the most absolute freedom as to his general course of action.

"3. First, I would state as the recommendation of their Lordships, that Professor SMYTH should consider the object of his expedition to be not so much to obtain specific and determinate results, as to ascertain what may be done, or what may be expected in future expeditions to places under the same atmospheric circumstances. The main thing is, to discover how much astronomical observations may be benefited by the removal of the injurious influence of the lower third part of the atmosphere. At the same time, there are some specific observations, requiring little time, and naturally falling in with the general series, which it is well to mention by name.

"4. Among these, the first beyond all doubt is to endeavour to ascertain whether the red prominences which have been seen on occasions of total eclipses of the sun, and which seem to be connected with the sun's body, can be seen upon the uneclipsed sun, when the atmosphere is so rare and so pure that the diffused light in the proximity of the sun's disk becomes practically insensible.

"5. It is very desirable that careful observations should be made on the zodiacal light, and that these should be continued through all hours of the night, and especially about midnight. Observations lately published have led several persons to suppose that the matter whose illumination exhibits the zodiacal light surrounds not the sun, but the earth; and this could probably be definitively settled on the Peak of Teneriffe.

"6. The scrutiny of the appearances of some double stars and nebulæ, and more especially that of the disks of the moon, the planets, and their satellites, obviously presents itself as an important object. Perhaps, however, it is to be desired that the observations should be so framed as to determine what can be done, rather than at present to carry out any laborious series of special observations.

"7. In the related subject of optics, it is to be desired that measures of the polarization of the light and determinations of the plane of polarization, be made in different parts of the sky, and be compared with similar observations made at the bottom of the mountain.

"8. It is also desirable that FRAUNHOFER's spectral lines should be observed with various elevations of the sun, and in different parts of the sky, and should be compared with observations made at the bottom of the mountain.

"9. The determination of the comparative horizontal intensity of terrestrial magnetism above and below would be useful, unless the magnetism of the mountain should vitiate all magnetic observations.

"10. A few observations of temperature at various times, radiation, moisture, and electricity, are to be recommended. These, like all those last mentioned, should be comparative.

"11. Advantage may be taken of a residence on the mountain for making such an examination as will decide whether the mountain is a favourable one for experiments on the attraction of mountains. It will be borne in mind, that if not favourable for determining the attraction north and south by means of the zenith-sector, it may be favourable for determining the attraction east and west by means of the transit instrument, provided that it is possible to carry a galvanic communication over the mountain.

"12. If the general tenor of the observations, which Professor SMYTH shall be able to make, leads him to think that material advantage may be produced to astronomy by the establishment at some future time of an observatory of more permanent character at a great elevation, the mountain may be examined for the purpose of deciding whether it is upon the whole a favourable place for such an establishment, and what point of the mountain will prove practically the best locality.

"13. In submitting to their Lordships these drafts of suggestions, I would beg leave again to refer to the opinion which I have expressed in article 2, that it is desirable that Professor SMYTH be fettered as little as possible by instructions.

"I have the honour to be, Sir,

"Your very obedient Servant,

(Signed) "G. B. AIRY.

"1856, May 29th.

"*Additional Suggestions for Professor* C. P. SMYTH, *by* G. B. AIRY.

"Observations for the height and duration of twilight.
Dip of the sea-horizon.
Refractions near the horizon.
Solar radiation."

II.—*Letter from Sir* JOHN HERSCHEL *to the Secretary of the Admiralty, dated Collingwood, 5th May*, 1856.

"SIR,—In reply to your letter of the 2nd inst., informing me that the Lords Commissioners of the Admiralty have been pleased to sanction a grant of £500 to meet the

expenses of an astronomical expedition to the Peak of Teneriffe, to be undertaken by Professor SMYTH of Edinburgh, and that their Lordships wish me to furnish them with any suggestions I may have to offer for the better carrying out the project;—

"1st. I have to state, that I consider the opportunity a very valuable one for obtaining an extensive and normal series of comparative actinometric observations, made *simultaneously* (strictly so) on the summit of the mountain and at the level of the sea, with actinometers provided with interior thermometers (not mercurial). These instruments, and the mode of using them, are fully described in the section on Meteorology, and forming part of the 'Manual of Scientific Inquiry' published by authority of their Lordships in 1849; the object being the determination of the proportion of the solar heat absorbed by the atmosphere between the two limits of altitude. Should circumstances permit, an intermediate station, about half-way up the mountain, would afford valuable supplementary observations. Such observations, taken at the time of the sun being vertical, would be very precious, but the series should be extended to every altitude of the sun down to the horizon.

"2nd. It has been stated, that at a place considerably lower than the actual summit of the Peak, there occur caverns on the mountain side, in which, though beneath the limit of perpetual snow proper to those latitudes, the temperature is always below the freezing-point. The fact (which is not without analogous ones elsewhere) should be inquired into, accurate observations made, and the concomitant circumstances carefully recorded.

"3rd. The opportunity will of course not be lost of ascertaining by comparative observations, with one and the same telescope, in England, at Orotava, and on the summit of the Peak, what degree of advantage, in point of optical performance, is obtained by change of climate, and by ascent into a clearer and rarer atmosphere. The selection of proper objects of comparison, such as nebulæ, clusters, double stars, &c., must be left to the observer's judgment.

"4th. The spots of the sun will probably be observed to very much greater advantage at so elevated a station, and by the aid of Mr. DAWES' eyepiece, their physical peculiarities may there be examined with every prospect of obtaining some distinctly new information. There, too, if anywhere, it may be possible, by careful management, to obtain a sight of the red protuberances from the sun's limb, which on the plains can never be seen but on the occasion of a total eclipse.

"5th. As Mr. SMYTH is an expert photographer, he should be provided with an apparatus for obtaining photographic impressions of everything worthy of record, *inter alia*, the great Dragon Tree of Orotava (supposed to be the oldest tree in the world), from several points of view. Of course accurate girth measurements of this most wonderful object, at several levels from the ground (defined by marks left on the trunk), will not be neglected.

"6th. The polarization of the sky light, at the summit of the mountain, should be carefully examined, and the point of maximum polarization, with respect to the sun's

place, determined with the greatest attainable precision *for homogeneous light* of some definite refrangibility, as well as the ratio of polarized to unpolarized light.

"7th. A very interesting series of astronomical observations on refraction might be made, should time be allowed, if a good altitude and azimuth instrument could be furnished, and erected at or near the summit; consisting in determining the form of the apparent diurnal orbit of a star passing through the zenith, and α Andromedæ would be an excellent star for this purpose. It passes *almost exactly* through the zenith of the Peak; and supposing the observer to be there in August, it rises about three hours after sunset, and reaches the zenith about as much before sunrise, affording the most favourable conditions for regularity in the disposal of the atmospheric strata.

"8th. The observer's attention should be directed to any instance of *lateral* refraction, like that remarkable case described by HUMBOLDT as having occurred to him at Orotava.

"9th. The temperature of the sea-water, taken up from about 10 feet below the surface, should be determined daily, or several times in the day and night, on and near the tropic, if possible, to the hundredth of a degree.

"10th. It would be most desirable also to procure thermographic representations of the solar spectrum (as described in my paper in the Philosophical Transactions, 1842), and to examine the 'fixed lines' of the luminous spectrum, with a view to ascertaining whether they, or any of them, originated in absorption of the earth's atmosphere.

"I have the honour to be, Sir,

"Your very obedient Servant,

(Signed) "J. F. W. HERSCHEL."

III.—*Letter from Lieut.-Col.* JAMES, *R.E., to the Secretary of the Admiralty, dated Ordnance Map Office, Southampton, 5th May*, 1856.

"SIR,—1st. I beg to acknowledge the receipt of your letter of the 2nd inst., informing me that the Lords Commissioners of the Admiralty have sanctioned a scientific expedition to Teneriffe, under Professor PIAZZI SMYTH, and requesting me to offer any suggestions which may occur to me for the better carrying out of the object in view.

"2nd. It is peculiarly gratifying to me to learn that so immediately after the conclusion of peace, an enlightened Government has turned its attention to the promotion of science.

"3rd. The special object which the scientific world have in view, when they urge the Government to avail themselves of Professor SMYTH's voluntary offer of his services, is to obtain that closer (so to speak) and more perfect view of the heavenly bodies which is to be obtained at a great elevation and in a purer atmosphere than can possibly be obtained in this or perhaps any other part of the world.

"4th. From Professor SMYTH's known powers as an accurate observer, and from the singular facility and felicity with which he is able to represent and describe what he

sees, I anticipate that this special object will be successfully accomplished by him.

"5th. He will of course be furnished with one or two of the best portable telescopes which England can furnish, for which he will require one or two tents, especially made for the purpose, and which, with the sanction of the Treasury, I could have made here; in addition to which he will require an order for the issue of two marquees or bell-tents from the Tower, or some other military depôt, for himself and attendants, with a supply of stretchers, bedding, and cooking utensils; and as the steamers for Teneriffe start from this port, I shall be happy to receive them here, and see that everything is properly provided to enable the Professor to carry on his duties effectually.

"6th. In the foregoing observations I have confined myself to the special object which Professor Smyth had in view, and the appliances to effect it; but Teneriffe, from its great altitude, its symmetrical form, its position on the confines of the tropics and the trade-winds, is the most remarkable landmark on the face of the earth, and its meridian was long ago proposed to be the first meridian for all nations; and I should truly rejoice if the Government, in addition to sanctioning the necessary expenditure for observations on the surface of the heavenly bodies, would also sanction the necessary expenditure for observations by which their mean density might be determined with more precision than it is possible it could be on any other spot on the earth.

"7th. My attention has been specially directed to this point of late; the primary triangulation of the United Kingdom has just been brought to a close, and from it we have deduced the form and dimensions of the earth. In the autumn of last year I had observations made at Arthur's Seat near Edinburgh, for the purpose of determining the mean density of the earth; the results of these observations and computations will be read at the Royal Society on Thursday next, the 8th inst. The determination of these points is of the very highest importance in physics; the size and density of the earth are our only units of measure by which we can calculate the distance, size, and density of the heavenly bodies; and I could not but feel how much more valuable and trustworthy would the observations which were made at Arthur's Seat have been if they had been made on the flanks of the Peak of Teneriffe.

"8th. The Peak of Teneriffe is in round numbers 5000 times greater in its mass than Arthur's Seat, and its attraction, as affecting the plumb-line, cannot be much less than twenty times greater. The Peak is also, from its form and mineral structure, peculiarly well-adapted for such observations, and I feel that if Her Majesty's Government would sanction the necessary expenditure, there is no scientific research which would be viewed with greater interest by the whole world.

"9th. The command of so large a body of trained observers and surveyors as we have on the Ordnance Survey, fortunately enables us to undertake this investigation at no great expense, and with little interruption to the progress of the National Survey. I do not anticipate that the party need be absent from England more than four months, and it would consist of not more than eight Sappers from the Survey, and about twenty

young Sappers from Chatham; but we should require the attendance of a convenient-sized steamer, under an experienced officer in hydrographical surveying, not only to take out and bring back the party, and to enable us to visit and supply the parties round the Peak from the different points on the shore; but also for the purpose of taking accurate soundings, by which the configuration of the ground under water might be known.

"10th. The observations which I have here contemplated, in addition to those undertaken by Professor SMYTH, are,—

"(1). To ascertain the difference between the geodetical and astronomical amplitude of an arc of meridian, drawn through the Peak, from which to deduce the mean density of the earth.

"(2). The difference in the time of vibration between a pendulum on the summit and near the level of the sea, from which we can also deduce the mean density of the earth.

"(3). The geological structure of the Peak, and its mean specific gravity.

"(4). Meteorological observations at different altitudes in the trade-winds towards the equator, and in the upper current from it.

"11th. The Government has now a large number of steamers fitted out and suited for this purpose; there can therefore be no more convenient, as there can be no more appropriate, time than this, at the close of a great war, for undertaking a scientific expedition, which will be hailed with satisfaction by the whole civilized world, and emphatically mark the return of peace.

"I have the honour to be, &c.,

(Signed) "HENRY JAMES,
Lieut.-Col. Royal Engineers."

Report of the Committee appointed by the Council of the Royal Astronomical Society, to consider the recommendation for the Teneriffe Expedition.

"The Committee recommend the following subjects as particularly desirable to be attended to, so far as they do not interfere with the more special objects proposed by Professor SMYTH:—

"1. The practicability of rendering visible the red prominences on the margin of the sun.

"2. Observations on the solar disk generally, including faculæ near the border, and the alleged diminution of light towards the edge.

"3. Observations of the disks of the planets, and especially of Venus, with respect to irradiation, and also to her atmosphere, and possible satellite and spots, with the view of determining her rotation.

"4. Observations on double stars and nebulæ, with the view of testing the effects of a purer atmosphere, with especial attention to Antares and his companion at the approaching occultations.

"5. Solar refraction, in reference to Professor THOMSON's theory.

"6. Determination of the constant of atmospherical refraction, by observation of zenith distance of circumpolar stars.

"7. Observations on the zodiacal light, with reference to recent theories.

"8. Observations to verify HUMBOLDT's remarks on the *lateral* oscillation of stars near the horizon, and on scintillations generally.

"9. Attempts to determine the polarization of the light of asteroids and faint planets.

"10. Observation of the fixed lines in the solar spectrum.

"11. The usual meteorological observations, especially of the humidity directly by DANIELL's hygrometer.

"12. Surface-radiation from various substances, and the intensity of solar radiation.

"13. The determination of the height of the Peak by barometer, and the lowest snow-line on different sides of the mountain.

"14. The distribution and limit of vegetation on the mountain.

"In proposing this list of subjects, the Committee do not wish to be understood as pressing *all* of them as of equal importance, but simply as suggestions subordinate to the main objects of the expedition, though they think the more material are Nos. 1, 5, 7, 10 and 12. With respect to No. 6, they also propose it only in case the Professor is prepared to undertake such a series of observations as would be necessary.

(Signed) "BADEN POWELL,
"ROBERT MAIN,
"24*th May*, 1856." "R. C. CARRINGTON."

"Royal Society, 3rd June, 1856.

"The President and Council of the Royal Society have learnt with satisfaction that it is the intention of Government to send an expedition to the island of Teneriffe, for the purpose of observing astronomical phenomena in a locality peculiarly favourable for that class of observations which are most obstructed by the action of the atmosphere. The nature of these observations, and the best mode of carrying them out, have already been maturely considered by Professor SMYTH, with the assistance of the Astronomer Royal, so that it is quite unnecessary for the Royal Society to offer any suggestions on that head.

"But while the astronomical observations for which the expedition was undertaken must be the grand object of the observer's attention, there are some other subjects for the investigation of which the expedition offers a peculiarly favourable opportunity. In consequence of the short time during which Professor SMYTH is likely to remain on the Peak, and the necessary devotion of his principal attention to astronomy, it would be useless to suggest any collateral investigations except such as could be carried out in a short time and with a moderate expenditure of labour; nor do the President and Council suppose that it will be found practicable to attend to all the suggestions they may make, especially as the expedition is so shortly to sail. The following suggestions are offered:—

"1. The determination of heights by barometric observations is liable to be influenced, to an extent at present unknown, by the state of motion of the air, and other similar disturbing causes. Much useful information on this point might be obtained by taking out three or four barometers, to be planted, one at the station chosen near the top of the mountain, and the others in different directions round the base, especially one towards the windward and another toward the lee side of the mountain, with reference to the prevailing winds. The barometers should be observed at the same hour several times during the day, and the temperature of the air, and likewise that of the mercury, unless the two may be assumed to be the same, as well as the dew-point, should be registered, the direction of the wind noted, and its velocity estimated, at each observation. It is supposed that persons might be found, who, either from an interest in the subject or for a small pecuniary consideration, would undertake the registration of the barometers placed at the base of the mountain. One or more barometers might be placed at different altitudes, should habitations and suitable observers be found. It is to be hoped that time may be allowed for an independent determination of the difference of altitude of the stations by triangulation or levelling.

"2. The temperature and hygrometric state of the air might be determined at intervals in ascending or descending the mountain, a portable barometer being read at the same time, so as to give the altitude, and the transitions from one aërial current to another, whenever they occurred, being noted. These results would be especially interesting for comparison with those obtained in the recent balloon ascents of Mr. Welsh, undertaken under the direction of the British Association, and the more ancient observations of the same kind.

"3. Interesting information might be obtained relating to the absorption of the solar rays by the atmosphere, considered with reference to their total thermic effect, by making observations at different altitudes with Sir John Herschel's actinometer.

"4. As some of the fixed lines of the spectrum appear to owe their existence to the absorption of light by the earth's atmosphere, it would be interesting to compare the lines seen at the mountain top station when the sun is low, with those seen about the middle of the day, and those again with the lines seen at a small elevation above the level of the sea; and it would add much to the interest of the investigation if photographic impressions of the lines could be taken.

"5. Certain observations seem to show that the atmosphere is to a certain extent opake with regard to the more refrangible of the solar rays, so that it seems likely that the spectrum would be found to be of greater extent, on the more refrangible side, on the top of a high mountain than below. This point could easily be decided by forming a pure spectrum with a quartz apparatus, and receiving it on a piece of glass coloured by uranium, or on some other substance possessing a similar property.

"6. Observations might be made on the polarization of the light of the clear sky as seen from the top of a mountain, especially with reference to the determination of the neutral point or points, if any exist.

"Many subjects of investigation relating to astronomy, physics, or meteorology, will probably suggest themselves to the observer when on the Peak, the selection and elaboration of which are best left to his own judgment. There are also various points of interest relating to the geology and geography of this region, which Professor SMYTH may possibly find time to attend to.

(Signed) "WM. SHARPEY,
Secretary."

(3.) *Execution of the Work.*

Having embarked at Southampton on board Mr. STEPHENSON's yacht 'Titania,' with all the instruments and baggage, we crossed over to Cowes for stores, and setting sail from thence on the 24th of June, reached Santa Cruz in Teneriffe on the morning of July the 8th. On July the 14th we ascended the mountain with the greater part of the instruments, and occupied a station (Guajara) on the circle of the "great crater," at the height of 8903 feet, from that evening until August the 19th. On the 20th we ascended to a more elevated station (Alta Vista) on the sides of the Peak, or central cone, at a height of 10,702 feet; from thence visited the top of the mountain, 12,198 feet in height; and finally descended to the sea-level on the 19th of September. On September the 26th we re-embarked in the yacht, and returned to Southampton on the 14th of October; having, with an absence from home of 113 days, spent so large a proportion as 65 days at the heights mentioned above.

The chief numerical results are contained in ten MS. books, as thus:—

Vol. 1. Astronomical and Physical Journal.
Vol. 2. Mountain Meteorological Journal.
Vol. 3. Reduction of the above.
Vol. 4. Sea-level Meteorological Journal.
Vol. 5. Reduction of the above.
Vol. 6. Illustrations to the Astronomical Journal.
Vol. 7. Results and Conclusions,—Astronomical.
Vol. 8. Results and Conclusions,—Physical and Meteorological.
Vol. 9. Results and Conclusions,—Geological, Botanical, &c.
Vol. 10. Photographs.

From the manner in which the observations are exhibited in the above books, they will be found, I trust, to explain themselves. In many cases they must be studied originally and in the full, to enable all their meaning and significance to be appreciated. In others, I may be able to save investigators some trouble, by collecting together all the measures of special phenomena, and indicating the results and conclusions to which they lead, as in the following pages.

No inconsiderable part of the thermometric and other meteorological observations on the mountain were made by the second mate of the yacht, WILLIAM CORKE, who accompanied me there, together with the carpenter, WILLIAM NEALE, whose services were of

extraordinary importance in repairing damages to instruments caused by the dry atmosphere above the clouds, and in adapting materials and means to the novel circumstances in which they were placed.

For the sea-level observations taken during the same period, all acknowledgements are due to the captain of the yacht (LOVING CORKE), who made the whole of the said observations himself, and with strict attention to the principles laid down to him.

Very lately I have had the pleasure of receiving from Teneriffe a large mass of tide observations, taken under the immediate superintendence of Don FRANCISCO AGUILAR, a Spanish civil engineer, engaged on the repair of the Mole, and inspired with the most laudable enthusiasm for the promotion of science. Finding that these observations have been made exactly in accordance with the desired instructions, and having personally examined the tide-gauge, erected for the purpose under the care of the Don and Mr. L. HAMILTON, I have great satisfaction in including the Spanish contribution in the present report.

CHAPTER II.

DEDUCED IMPROVEMENT OF ASTRONOMICAL VISION WITH HEIGHT.

(1.) *Vision and Definition.*

This important question was quickly and satisfactorily settled on Guajara; for by frequent trials during several years in Edinburgh, I had ascertained the range of vision with the Sheepshanks telescope to extend to the 10th magnitude; I had never, for instance, been able to see the companion of α Lyræ (11th magnitude), even when selecting the most favourable nights, and with the star only 5 degrees from the zenith; while with the same telescope and the same eye on Guajara, at 8903 feet of height, and with α Lyræ 25 degrees from the zenith, the companion was always and easily visible, more so than the companion of Polaris (9th mag.) used to be in Edinburgh. Smaller stars still were also observed, as C of 5 Aquilæ (14th mag.), D of 13 Lyræ (12th mag.), B of δ Aquilæ (12th mag.), B of 128 Anseris (13th mag.), B and C of β Equulei (13th and 14th mags.). Stars of the 15th and 16th magnitudes, looked for, were not seen, as was the case also with one of the 13th magnitude.

An extension of telescopic vision through four magnitudes is thus made out, and would be an inestimable addition to our larger classes of telescopes; for much of the advance seemed to be owing to improved definition, as well as to the transparency of the air.

This fine definition was shown in the perfection of the images of the stars, which, five nights out of six, exhibited clear little disks surrounded by regular rings, when viewed under a magnifying power of 150, and contrasted most favourably with the amorphous figures that the same telescope had always given in Edinburgh. When there, indeed, I had been at a loss to understand how accurate measure could be applied to the double stars; but on Guajara the appearance of every double star seemed, by its finish and exactness, to provoke one to apply a wire micrometer to it.

The usual test of definition, the separation of close double stars, especially when there is much difference in their size, was tried at the Alta Vista station with the Pattinson telescope. I cannot, unfortunately, state comparative results with this instrument; for though I visited its hospitable owner in England on three different occasions, at intervals of several months, yet the sky was invariably clouded. We have therefore only to look to the aperture of the object-glass, 7·25 inches, and compare its performances on the mountain with those of instruments of the same size elsewhere.

ε Arietis, λ Cygni, 52 Arietis, all double stars, and with the distance of their components given in the "Cycle" at under 1″, were completely separated. B and C of γ Andromedæ, with a distance of 0″·5, night after night, and on one occasion at so large an hour-angle as $4^h\ 30^m$, were seen divided, but not exactly separated; for although there certainly was a dark line between them, yet the disks were mutually compressed on that side to a small extent. A diagonal eyepiece with a transparent reflector did separate the two disks completely, by making them smaller; but the definition was so much injured, that this testimony to the duplicity of the star and the excellence of the telescope, was not deemed more satisfactory than that afforded by the direct eyepiece with its larger and brighter stellar images.

The excellence of definition at Alta Vista seemed to extend over the whole sky, and was still most satisfactory when, toward morning, I examined Saturn heliacally rising in the east. The fine division of its outer ring, and the transparency of the dark ring, were abundantly manifest; but the general perfection of finish as it were of the borders of both ball and ring, struck me as the most noticeable point; for even with a power of 500, I could not fancy anything more clear at its edges than they were.

These observations were repeated on Saturn during several mornings, and are all the more noteworthy, since that is about the time when telescopic definition in most observatories becomes exceedingly bad. On the mountain the sun was seldom well defined, and his excessive radiation seemed to disturb the air, and in a manner that often lasted in the western regions long after he had set; but night usually succeeded in quieting the commotion.

(2.) *Agents in producing good definition.*

Thus far the facts of observation have been stated; and the main explanation of them is evidently the other fact, that when looking at the stars on the mountain, we were not looking through those grosser and denser strata of the lower regions of the atmosphere through which ordinary observers must look. On the mountain we found another circumstance operating, whose existence is not generally suspected: this is the prevalence of excessive drought. Had there been any actual formation of dew, there would have been difficulty in keeping the glasses free; and with the smallest portion forming on them, adieu to all delicacy of vision. But in a region where the average depression of the dew-point was, as we found it, the unheard of quantity of 40°, and where it was not unfrequently above 50°, the formation of dew was physically impossible.

Hence some of our best observing nights were on occasions that in a moister atmo-

sphere would have been impracticable; for the calmness of the atmosphere and the radiation of the sky, inasmuch as depended on them, tended powerfully to the formation of dew. Thus at Guajara, on the 4th of August, when an unsurpassable definition seemed to reign all night long, and there was no wind and no cloud; and in so far there ought to have been dew on the object-glass, whose temperature must have been brought down far below that of the surrounding air,—for the radiation of the sky amounted to 17° (that is, the temperature under cover was 50°, and the temperature of a black-bulb thermometer exposed to the sky was 33° at 2 A.M.),—yet the temperature of the dew-point being at the same moment only 19°, no clouding of the object-glass took place.

Comparing our observations on the mountain with those of Mr. WELSH in his balloon ascents, and the more ancient observations from DE LUC and SAUSSURE downward, this excessive dryness above the clouds may be considered a universal phenomenon; though the absolute height at which it most signally prevails, depends on season and other effects. Thus in Teneriffe, throughout the summer, the dry atmosphere may be secured at so small an elevation as 5000 feet; but in autumn and winter (see the Mountain Meteorological Journal for September the 14th), we should have to rise occasionally so high as 12,000 feet, in order to reach it.

(3.) *Daylight Observations of Stars.*

Sundry notices of stars picked up during the day with the Sheepshanks telescope on Guajara are scattered through the Astronomical Journal, but its performances in this way were not strikingly better than in Edinburgh. Some allowance must undoubtedly be made for the very untoward circumstance of the telescope on the mountain being exposed in the open air and bright sunlight, while in Scotland it had been employed in a dark room, with only a small aperture for vision in the roof. Over and above this cause, much of the want of greater success in the day observations must be attributed to illumination of the atmosphere by the sun. True, that the atmosphere becomes more transparent as we ascend, but the brightness of the sun increases at the same time, and the multitudinous reflexions of its light from motes in the air increase more intensely still.

Hence, as long as the sun is above the horizon, daylight on the mountain is almost as fatal to stars as on the plains. The blue of the Alpine sky, which has been spoken of by travellers as something so deep as to verge on black, we did not find even on the culminating point of the Peak, at 12,200 feet of altitude, to be anything extraordinary. When observing the sky in immediate proximity to the sun, as for the eclipse red prominences, the field of view was so intensely bright, that a very dark glass was necessary to protect the eye; and even when using the faint reflexion from the transparent mirror of a sun-eyepiece of the Pattinson equatorial, considerable practice was necessary before one's eye could withstand the glare.

This rendered a search for stars very near the sun quite hopeless; and even when

looking for them at greater distances, as 10 and 15 degrees, there was ever more or less of a luminous pattern on the object-glass, caused by the all-powerful sunlight striking on microscopic imperfections on the surface.

With all this, however, I observed by day many more stars than I had ever done in Edinburgh; but the more marked result was, the far greater brightness of the bright stars. The preponderance of Sirius, for instance, above all other stars, was never so powerfully manifested to me before; and from his excessive and staring visibility, one came down at once through an immense number of measurable gradations to Arcturus, the next brightest star visible, and perhaps arrived at total invisibility with a star of the third magnitude.

(4.) *Naked-eye Observations.*

The stars shone brilliantly, as seen from Guajara, and caused the dome of the skies to appear resplendent with glory; the Milky Way was a magnificent feature in its scenery, and the zodiacal light towards morning was still more remarkable. Jupiter also was surpassingly brilliant when high in the heavens after midnight; but I could never see his satellites with the naked eye, not even when eclipsing the planet behind a distant lava ridge. When treating the bright part of the moon in a similar manner, the illumination of the dark part appeared conspicuously, though the first quarter was past. With the new as well as the old moon, when forming a crescent, the brightness of the surface was such, as, acting by irradiation on the eye, to give an appearance of unnatural bluntness to the horns. She gave one, moreover, at once and visibly, the real idea of being closer than the stars; while the "shooting-stars," of which by the way we did not see any displays remarkable either for number or brightness, appeared absurdly close; and, having a reddish light, looked even like sparks of fire flying through the air.

We were much struck on the mountain by the quiet and steady planetary light of the stars, and were inclined at first to say that they did not twinkle; but we soon found that they did so, though to a much smaller extent than in the plaisn below. Having lately become acquainted with Professor Dufour's method of applying the principles of numerical observation to the scintillation of stars, and the rich results that he has already deduced from very simple beginnings, I regret that I did not attempt something of the same sort on the Peak; though perhaps nothing short of his own skill and experience would be required to do justice to the natural capabilities of the place.

(5.) *Qualities of the Atmosphere.*

The astronomical qualities of the atmosphere may be divided into two species,—the immediate or particular, as wind, fog, &c.; and the general, as distant clouds, haze, and other aërial impurities.

Wind is usually a terrible drawback on the availability of mountains for observatory purposes, and the tops of the lower hills in Teneriffe, at about the level of the trade-wind cloud, are swept by it with terrific force; but above that height, the wind, still preserving the same N.E. direction, continually decreases in strength, until it reaches a

neutral stratum below the S.W. wind, which appears there to be always the direction of the upper current in the atmosphere, in the summer at least, for which season alone my descriptions are intended to apply.

The height of this neutral region would seem to vary much; sometimes it was below, but much more generally above 9000 feet. Hence we had more N.E. wind than S.W. at Guajara; but being in the neighbourhood of the neutral stratum, neither wind was felt in great force, except on one occasion, when for several hours in the morning the N.E. wind blew with a velocity of from twenty to thirty miles per hour.

This circumstance in itself confirmed the conclusion already drawn from the number of days that each wind was felt, viz. that we were much nearer the N.E. than the S.W. current. And finding that in proportion as the former (N.E.) predominated, so did faint dusty impurities in the air, and bad definition, we proceeded to establish a second station at "Alta-Vista," at the height of 10,700 feet. Our earlier experiences on moving there confirmed the truth of the idea, for there was on the whole less wind than at Guajara, and it was more evenly balanced between the two directions. Our later experiences at that station included the setting in of autumn, which broke in upon all the regularity of the summer weather, and need not here be alluded to further, as our experiment was only intended to utilize the summer season.

With wind then we were visited but moderately, and we were equally fortunate with regard to fog or mountain clouds; for though they existed below and appeared daily, dense, closely packed together, and rolling upon each other, they showed no tendency to rise higher than 4500 feet. With this depression of the mountain cloud, including cumulus, cumulostratus, and nimbus below us, we had but the thinner forms of cloud, cirrus, cirrocumulus, and some cirrostratus, ever at any time floating above us, or interfering with the view of the heavens. These only appeared abôut once in five days in any considerable quantity.

A more important quality of the atmosphere was caused by the dust-haze, which was ever more or less present, though sometimes in vastly greater quantities than at others, and was precisely that which injured, or rendered impossible, daylight observations of stars. Where this dust-haze came from or went to we could never tell; but, when present, we could easily distinguish its banks, or strata, as they stretched away and condensed in perspective towards the horizon. There were often several strata, one above the other, and mutually separated by very clear and sharply-defined spaces of atmosphere. When, as was sometimes the case, the summits of Grand Canary, or of Palma, rising high above the sea of clouds, pierced also these upper strata of dust-haze, we had, from Guajara, the curious phenomenon of zones of blue mountain alternately distinct and again indistinct almost to invisibility, and yet no cloud or other recognized impurity of the atmosphere intervened.

Being above much of this dust, though perhaps not the greater part of it, we were evidently better off than an observer at the level of the sea, when pointing to a zenith object; but for a horizontal one we were worse off, from often being *in*, and then look-

ing *through* the whole plane of the stratum, and so experiencing the maximum of its light-stopping effect.

Hence the occasional deterioration of sunrise and sunset were infinitely greater than anything that occurred at noon; and on some days, when the sky was perfectly free from cloud, and the sun had been distressingly hot and bright when high in the sky, yet it had almost become invisible before it set. It was seen, though made out with difficulty on such occasions, through a darkling, yet luminous haze of dull lemon-yellow colour; but what it set behind, or when exactly it did set, there was no ascertaining.

The next evening perhaps the atmospheric dust had removed, and the change in the sunset was magical. The orb radiated hot and shone bright up to the moment of going down, sometimes behind Palma, showing hills of rich dark purple; sometimes behind the rollers of the cloud sea, clearly visible to the extreme verge of the horizon. Then, too, in place of the uniform yellow colour of the dusty sunset, the most gorgeous scarlets, yellows, and blues took its place.

To eliminate this dusty medium would be of the utmost importance to the further improvement of astronomical observation, and may be considered the greatest and most subtile difficulty which the observer has to deal with; and it is probably general over the world, as on the South African mountains, at heights of 5600 feet, the phenomenon was almost as notable as on Guajara. From Dr. MASON's observations of solar radiation in Madeira, and from the relations given to me by inhabitants of Teneriffe as to the periods of the year when the Peak is seen most clearly, I am disposed to think that there is least of this dust in the atmosphere in the latter end of the winter and the earlier part of the spring. The latter, if not the former also, would probably be a practicable time for mountain observation; for one of the most remarkable results of our meteorological inquiries, is the indication of the seasons being nearly two or three months earlier at a height of 10,000 feet than at the sea level; so that the difference of temperature in the spring, between the two zones, is by no means so great as in autumn.

CHAPTER III.

ASTRONOMICAL OBSERVATIONS PROCURED.

(1.) *Double Stars.*

The Astronomical Journal contains many notices of double stars, but as they were merely for the purpose of testing the performance of the instruments, the nature of the objects was always assumed to be known (the "Cycle" being adopted as authority), and our aim was rather to take an eye recognition of as many objects as possible, than to apply rigorous measure to a few. Several cases of change in magnitude, distance, and position were however encountered, and are given; many stars were also observed for colour, to compare with observations below. These will be found duly entered in the

Journal; and the only remark that need be made here, is, in connexion with the astonishing visibility of the companion of Antares, which escaped STRUVE, with an instrument wherewith he discovered the duplicity of B and C Andromedæ, and so many other difficult tests. When we bear in mind the great altitude of these latter stars in Russia, and the very low altitude of Antares there, the case may be taken as a strong illustration of the importance of eliminating atmosphere from observation in every possible way; not only by climbing up a mountain, but by each observatory confining itself to the objects in the neighbourhood of its own zenith.

(2.) *Moon and Planets.*

At Guajara, with the Sheepshanks telescope, there were many tempting opportunities of delineating parts of the moon's surface; but the small power of the telescope prevented such work being as good disposal of my time, as many other observations that equally claimed attention. Moreover there was so remarkable a tendency of bright points of the lunar craters to form stellar disks and rings, that I was additionally induced to defer anything in this line, until the Pattinson equatorial with the transparent glass reflector-eyepiece should be erected.

This instrument was established at the Alta Vista in September, but the last quarter, which was to have been the lunar observing period, was interfered with by the premature setting in of autumn. In the first quarter of that month we had several opportunities, but not many or good ones, as the moon was then very low in southern declination, and the lava ridges rose high to the west of us.

Those few views, however, with magnifying powers from 160 to 560, made a most vivid impression on the minds of all at the station. There have been doubts expressed by some geologists, as to whether the circular cavities in the moon are craters; had they enjoyed these opportunities at the Alta Vista, they would have renounced such doubts, so many and so striking were the analogies between the craters of Teneriffe and those we saw in the moon. Among the most characteristic perhaps of the resemblances, is the greater steepness of the inner over the outer wall of every cavity or ring-shaped mountain; again, the precipitous ledges, and often the conchoidal bays and recesses of the inner wall; and the generally level floors of the cavities, with here and there a peak raised upon, or a little cup-shaped cavity established in them.

But the telescope showed over and above those well-known features, such an infinity of detail, that though I tried once or twice (see the view of Autolycus in Plate XXXIV.), I found it quite impossible to make a proper drawing of any notable part, in the contracted space of time between darkness and the moon going behind the lava ridge. Half a night would have been short time enough. In this department there is indeed an immensity to accomplish; the clear air of the Peak would be most favourable; and the opportunity that the astronomer would have, probably for the first time in his life, for ascertaining the distinctive forms of terrestrial craters from eight miles in diameter to 300 feet, would enable him to appreciate better the minute revelations of

the telescope. Of all the subjects connected with the lunar surface, to which attention may be directed, none perhaps is so important as the detection of what may be called the dynamic wrinkles of lava streams. These at once distinguish the lava stream from the avalanche of stones; and, as would appear on the Peak, lead to much insight regarding the temperature, fluidity, and order of the emitted streams. From the small size, however, of such wrinkles at Teneriffe, the successful observation of them in the moon would demand the best of existing telescopes, the highest magnifying power, and a rarefied mountain atmosphere.

Jupiter near the zenith was a sight very different from anything that European astronomers have had for many years past; I attacked it therefore with zeal as to optical features. At Guajara, with the Sheepshanks telescope, it was remarkably well defined, the belts clear, and the shadow of a satellite occasionlly crossing the disk was strong; but with the exception of a scolloped or festooned appearance in one of the belts, nothing new was seen. The interpretation of this peculiarity was left for the Pattinson equatorial at Alta Vista. There, with a power of 360, the bright spaces between the belts resolved themselves into masses of cumuli, cumuloni, and cumulostrati,—the drift doubtless of the Jovian trade-wind,—in their forms and gatherings so precisely like those which the terrestrial trade was accumulating round Teneriffe below our feet, that I could not avoid applying the same name to similar forms.

Three drawings of these appearances—they might almost be called revelations—in Jupiter are inserted in Plates XXXIII. and XXXIV. The originals were begun and finished at the end of the telescope, and each was made on a different evening, and without any reference to the previous views; so that the one may be used against the other, in determining the probable error in the representation of any particular feature of interest. Due allowance must of course be made for the change of the mean meridian each night; indeed during the time occupied in the drawing, the shifting of the whole of the forms, from rotation of the planet, was most perceptible without applying measurement; but over and above this, there were minute yet indubitable changes of shape in the cloudy appearances during two hours.

Of Saturn two drawings were made, but beyond satisfactorily showing the fine division of the outer ring, there was little to be done on account of the low position of the planet. One of the drawings, however, may be referred to (vol. 6, page 28) for the appearance presented in the telescope; the second was a mere sketch taken the following night to test the characteristics of the first.

A single drawing should not be looked on, by itself, as of importance in the present state of astronomy; for how can others than the artist prove the reality in nature of anything they may find in that one document, when this alone is before them? A bad designer will often unconsciously give an erroneous figure; and though intending to show perhaps the blurred outline he actually saw, may yet, by using a pen in place of a brush, represent the erroneous appearance as having all-perfect definition, and cause the juxtaposition of full white with deep black: and if he has put in these things and a

few others also by slips or bad drawing, we must take the whole as he has given it implicitly, or reject it entirely.

If astronomical drawing is to take a similar trustworthy and trusted place to numerical observation, in its own branch of subjects, we must in the first place with every man's work, eliminate errors in drawing and imperfections of the means and medium employed. How easily much of this may often be accomplished by *two* drawings, may be well seen in some of the photographs in the book of illustrations; for having been taken with stereoscopic intentions, they are all double. Hence, is there some doubtful mark in one? we have only to look to the other; and if the mark was in the scene itself in nature, it will likewise appear in the second view as well; but not so if it were merely a fault or imperfection in the surface of the plate.

After this first step has been accomplished, comes the more difficult affair of eliminating the personal and instrumental equation, from which source of error no object in the heavens has suffered so much as our present subject, Saturn. Thus the elongation of Saturn's rings in old drawings, not confirmed by micrometrical observation, may be mainly, if not entirely, attributable to the earlier observers—in their desire to intensify their discovery, and to prove that they had a clear perception of the sky intervening between the inner border of the ring and the ball—having pulled out the ends of the ring much further than they were justified; just as a sketcher invariably increases the steepness of all his mountain slopes. Again, up to even the last few years, the published drawings of Saturn, with a few bright exceptions, as the HERSCHELS', have exhibited such erroneous ellipses—that if the shape and dimensions of his rings and their divisions were to be computed on such testimony—they would be found to be endued with more anomalous deviations from their nearly circular form, than any one has ever ventured to attribute to them, and which the artists themselves had never intended.

To improve this state of things, Mr. DE LA RUE has lately not only given us such admirable drawings, as stamp him as the artist *par excellence* of Saturn, but he has, by his extensively distributed diagrams, produced a sudden and general improvement in all the current delineations of the planet.

My drawing, I find, approximates pretty closely to his, but in some of the smaller features inclines more to Captain JACOB'S view, as thus,—1st, the principal division is not perfectly black, but of the tint of the dark ring; 2nd, the fine division is not accompanied by a bright band; 3rd, the dark parts of the ball do not take accurately defined zones; and 4th, the shadow of the ball on the ring is remarkably sharply defined.

(3.) *Eclipse red prominences.*

Under the date of September the 9th, in vol. i., or the Astronomical Journal, will be found particulars of what may be an observation of one of the eclipse red prominences; but as the view of it was uncertain in the extreme, and all the other attempts that were made were entirely unsuccessful, I think it better to allow that this department of our work was a failure,—a failure not from any deficiency of the instruments, though these

might be further perfected, but from the qualities of the atmosphere, and chiefly from the dust-haze which was found existing in dense strata far above the clouds of the north-east trade-wind. The most likely method therefore to follow out on a future occasion would be, to try the experiment earlier in the season, when there is less of the haze existing; or to try some mountain higher still than Teneriffe.

(4.) *Solar Photography and Polarization.*

All our observations of the sun laboured under the inconvenience of being performed in the open air, and freely exposed to the direct solar rays: to guard against these the observer's head and the eyepiece were enveloped in a black bag. When this was accomplished, then came the greater difficulty of the excessive heating power of the sun, connected with its powerful radiation on a mountain. The eyepieces became so hot that they could not be touched, and the black bag was continually getting burnt, and with its smoke, irritating the observer's eye.

Somewhat depending on these untoward accompaniments, which might be much relieved on a future occasion, the definition of the sun was invariably worse than that of every other object in the sky. The year 1856 was, however, so near the minimum of solar spot-producing disturbance, that little of importance ever appeared on the disk. The only thing that I would particularize, is the "silk marking" observed on September 13th.

This was a feature almost defying any attempts to delineate by hand and eye, but should yield one would think to photography. Accordingly, with the assistance of the yacht carpenter, I improvised a photographic box to fasten on the end of the telescope, with a spring trigger to make an instantaneous opening and closing of the aperture. But success was small by reason of,—1st, the wooden box being often heated to smoking; 2nd, the shaking of the telescope; and 3rd, the rapid vibrations of the air causing bad definition.

Making the best of these circumstances, definition was still unprocurable, until by a series of experiments, the very unexpected result was found, that the chemical focus of the telescope was ·5 *inch longer* than the visual.

This circumstance seems to settle the question, that the rays which produce the photographic picture are by no means the luminous, and may, or may not, give us an idea of what we see with the eye. The black photographic effect of bright yellow is well known; and a similar diversity, and more in point with regard to the possibility of obtaining good solar photographs, was offered to me frequently in Teneriffe, chiefly in the lowlands, when taking photographic landscapes on collodion. It was this: a distant mountain range was seen with the most perfect definition of innumerable details about its flanks; the bushes, the cliffs, the dykes in these were distinct and even prominent to the eye; yet in the photographs, nothing but the faint, though well-defined outline of the mountain appeared against the sky; as if, in place of the sun shining on the mountain, it were on the other side and throwing the ridge into the shade. In a word, the

aërial effect was intensely exaggerated in the chemical medium, with every increase of distance and illumination. Of the latter, a good instance was shown in the facility with which at twilight a good photographic image of the moon was obtained; while by day, no matter how clear the moon shone out to the eye from the deep blue vault of heaven, no impression whatever could be procured*.

After meeting with these indubitable instances of the distinction between actinic and optic images, no photograph would be admitted as a decisive evidence on a certain point suggested for inquiry by the Astronomical Society, viz. the brightness of the centre as compared with the borders of the sun. But whether forming the sun's image on a screen, or looking at it direct, there was never the slightest doubt on my mind or my eye, as to the centre being very much brighter than the border. The centre was also whiter, the border being yellowish; and it was not at all from this cause that the borders were thought to radiate less light, for the difference was something far greater than variation of colour could explain. This experiment may be perhaps taken as conclusive: with the transparent-reflector eyepiece of the Pattinson equatorial, the field of view having a stop with a small perforation of about 3′ in diameter, I found that I could bear perfectly well to look at the border of the sun without any coloured glass; but I could not with impunity allow the stop to pass over the central regions of the solar orb, by reason of their surpassing brightness.

This result is confirmatory of the conclusions, I believe, of every observer but one, M. Arago; and he arrived at his unique view by means of a photometer, based on his polariscope; an instrument which I was also requested by the Astronomical Society to use on the mountain, and which I did not find very satisfactory.

The polariscope was arranged by its ingenious inventor to be applied to the eye end of a telescope, and doubling the image of any luminous object in the field, to colour them complementarily if they contained polarized light to a sensible degree; and this M. Arago is stated to have ascertained to be the case with planets and comets, but not with the fixed stars.

By Mr. Airy, the Rev. Baden Powell, and Mr. Cooke of York, I was furnished with various polarizing materials capable of being fitted up into such an arrangement; but on neither planets nor satellites, viewed with the naked eye, the finder, or the Pattinson equatorial, could I get the smallest indication of complementary colours. The planets in question were certainly not favourably disposed for the polarizing angle of their reflected sunlight; and before the moon arrived at that part of her orbit, the summer weather had broken up, and brought all our observations to an end.

(5.) *Rising and Setting of the Sun.*

Accurate observations of the time of rising and setting of the sun I had intended to make, under expectation of the phenomenon taking place behind the sea-horizon; but this line was never once visible during our whole stay on the mountain. In place of it,

* Further still, it was found that the photographic plate feels and renders at once all those additional rays, which in Stokes's spectrum the eye cannot perceive without the assistance of uranium glass.

was invariably the spurious horizon of the great stratum of N.E. clouds, at a varying height of perhaps 3000 to 5000 feet, and seen at Guajara under a zenith distance varying from 91° 5′ to 91° 11′.

The cloud attached to the mountain was not more than 2500 feet in altitude, and seldom stretched more than two or three miles away from it; so that what portion of sea was visible between its termination and the beginning of the sea-cloud, was, from our station, many degrees below the horizon, and quite useless for altitude purposes. In the case of the cloud floating over the sea, on the contrary, the extent from the mountain seemed illimitable; and from what we had seen for several days before reaching Teneriffe, we had every reason to believe, that generally round about that island, but chiefly towards its N., N.W., and N.E., a cloud stratum extends almost uninterruptedly for several hundred miles, always at the same height above the sea, and of the same generic character, or strikingly like the "cumulonus" of Admiral FITZROY (see Plates XXX. and XXXII.).

The form was not improbably a consequence of the mechanical action of the trade-wind on the cloud-material; and though the rollers of mist, moving along always rapidly from N.E. to S.W., often had intervals between them when examined in *plan*, yet viewed as they were in extreme perspective on our visible horizon, no gaps were seen in that position; while their substance, condensed apparently by distance, made them form as opake an edge for the sun to rise behind, as a snowy mountain.

Although, then, the *absolute* time of sunrise so observed would not have been capable of geographic truth, its *duration* could be taken pretty well. All the more extraordinary therefore is the account by a celebrated traveller, that the one sunrise which he observed from a height of 11,000 feet on the Peak of Teneriffe, had the remarkable anomaly of occupying upwards of eight minutes.

Subsequent observation at the same spot cannot prove or disprove any exceptional mirage that may have occurred to a former observer; but it may indicate whether the locality is frequently liable to such extreme dislocations of refraction; and with this view, the rough naked-eye observations which I used to take at Guajara for meteorological purposes, and which are entered in vols. 1 and 2, may be examined, and will be found to show no anomaly of the sort on any occasion. A characteristic feature of mountain sunrise and sunset used certainly to be the very visible flattening of the solar orb; but this was a constant and normal phenomenon; and if it reached, by sextant measure, so large a quantity as 5′, that was but the proper refraction-effect, due to a zenith distance of over 91°.

(6.) *Duration of Twilight.*

Observations for the duration of twilight were found capable, on being actually tried, of more precision than might have been expected; two minutes + or − appearing to include all uncertainties as to the vanishing of the last trace of the sun's light in the west, or its appearance in the east, the zodiacal light alone excepted; but this quantity does not include certain natural causes of difference in one day from another, which will be found to vary much more.

At Guajara.

Twilight. Duration of, at sunrise.	h	m	Twilight. Duration of, at sunset.	h	m	s
July 22nd	1	2	July 17th	1	10	0
			July 21st	1	22	0
			July 23rd	1	26	0
			July 26th	1	22	30
			July 27th	1	19	0
			July 28th	1	16	0
			July 29th	1	22	0
July 31st	1	2	July 30th	1	21	0
August 2nd	1	13	August 1st	1	21	0
August 8th	1	17	August 2nd	1	18	0
			August 3rd	1	16	0
			August 17th	1	19	0
			August 18th	1	14	0
Mean, July 31st . . .	1	8	Mean, July 30th . .	1	19	0

At Alta Vista.

Twilight. Duration of, at sunrise.	h	m	Twilight. Duration of, at sunset.
August 22nd	1	9	No sunset visible at this station.
September 8th	0	54	
Mean, August 31st . . .	1	2	

The difference of duration observable here between the morning and evening twilight is remarkable, and may be partly owing to the difference of intensity of the zodiacal light, which in the evening was barely visible, but was in the morning so bright as to prevent the very first trace of dawn being perceptible.

The following are a few of the additional observations made respecting twilight at Guajara:—

On the morning of the 8th of August, the first symptom of colours was distinguishable nine minutes after the first appearance of light; while in the evening of July 17th, and on July 26th, the colours were on each occasion distinguishable to within five minutes of the cessation of light.

Further, on August 17th P.M., eighteen minutes before the end of twilight, its altitude to the extreme blue was found to be 9°. And again, on August 18th P.M., at twenty-one minutes before the cessation of twilight, the altitude of the extreme blue was found 9°, and to the extreme red 3°; while at eight minutes before the cessation, blue colours were alone visible, and reached 3° high.

At the latter periods of twilight, I had some confidence in attempting to measure the

altitude, but not at the earlier periods, when the light was far too diffuse and uncertain as to its boundaries.

(7.) *Zodiacal Light.*

At Guajara the zodiacal light was observable both east and west: at Alta Vista only in the east, on account of obstructions in the horizon westward. Notices of observations of this phenomenon will be found in the Astronomical Journal under dates of July 23, 26, 30, 31, and August 2, 7, 8, 12, 18, and September 2, 4, 5, 6, and 7. The objects proposed were, in the first place, to measure the place of the apex of the light; its length, breadth, and shape, and its angle with the horizon; and in the second place, to note any additional circumstances that could be made out bearing on recent theories.

In the western direction the appearance was very faint, but it was certainly real; and of three observations taken about half an hour after sunset on July 26 and 30, and August 18, we have the following mean quantities:—

For August 4th, at 17^h sidereal time	Length from horizon	50°
	Angles of inclination to horizon .	31
	Apex in ⋀ $13^h\ 26^m$ and D−10°	
	Length from sun	71
	Degree of brightness	¼ of the Milky Way.

The greatest probable error of any of these observations, including all causes, natural as well as personal, may be ±6°, and within such limits, and not to those of the last degree given, we may assume that the plane of the light is shown to be nearly coincident with the ecliptic.

In the eastern direction, the Guajara observations on July 31, August 2, 8, and 12, give, for the mean date of August 5, at $0^h\ 50^m$ sidereal time,—

Length from horizon	62°
Breadth of base	24
Angle with horizon	75
Apex in $3^h\ 48^m$ ⋀ and D+21°	
Length from sun	76
Brightness	Milky Way ×2

The angle of the ecliptic with the horizon at the same time being 70°.

At Alta Vista, observations obtained on September 2, 5, and 7, give for the mean date September 5 at 3^h sidereal time—

Length from horizon	63°
Breadth of base	27
Angle with horizon	79
Apex in ⋀ $5^h\ 20^m$ and D+17°	
Length from sun	84
Brightness	Milky Way ×3

The angle of the ecliptic with the horizon being 78°.

The brightness stated is that of the brightest part of the whole mass, which was usually some 20° to 30° below the apex. This point was rounded off, and the sides leading up to it were convex on the outside, in as far as one can speak certainly of such faint light; and tended much, by the regular and complete symmetrical form which they indicated, to distinguish it from the admixture of the Milky Way which crossed it. I could, however, at times fancy that there was a sort of wisp of the last degree of faintness stretching from the apex some 50° further across the sky; and on one or two occasions could almost persuade myself that it stretched all across the sky to the opposite horizon, but could never satisfy myself that it was not fancy.

Respecting alleged observations of the zodiacal light at midnight, the result of Guajara and Alta Vista is, that it was decidedly not visible there either east or west at that time (see August 7 and September 4); *i. e.* nothing certain, nothing that seemed either worth observing or even possible to observe; and assuredly nothing approaching the visibility of even the faintest part of the area, included in the ideal outline drawn each night on the sky, when it was seen E. or W., so as to include everything that could be at all acknowledged for zodiacal light. Westward it was not seen in the evening within three hours of midnight; but eastward, and on the high elevation of Alta Vista, something was just visible at about 1 A.M.; a difference explainable by the already stated numerical results, where the length from the sun in the eastern sky is given at 13° longer than in the western, and the brightness at twelve times greater. The midnight observations may also be considered conformable to the absolute solar lengths found at other times, viz. 71° and 84°.

If, then, at midnight nothing was seen, and at the best period of visibility afterwards, viz. from 3 to 4 A.M., the greatest measured solar length of any acknowledged portion of the zodiacal light was 84°, it follows that a glow occasionally seen in the western sky at that morning hour, could not be the other end of the zodiacal light; for that would imply a length in the end, previously found the shorter, of upwards of 170°. The glow in the west, then, during the morning exhibition of the zodiacal light in the east, is but a reflexion of the latter on the atmosphere, and was closely paralleled on several occasions by similar reflexions of lunar dawn.

On August 18th there was observed with the lunar dawn a circumstance that looked at first very much like a lunar zodiacal light. At $17^h\ 5^m$ the moon's twilight was visible as a low flat elliptical arch of faint light; at $17^h\ 12^m$ it had manifestly grown pyramidal or pointed above; at $17^h\ 15^m$ the point had extended itself into a cone, all of the faintest light, 30° high and some 12° broad; at $17^h\ 20^m$ the moon rose. The cone looked exceedingly like a lunar zodiacal light; but on measuring its angle with the horizon and finding it always 90°, while the angle of the ecliptic at that part of the sky was only 38°, the appearance was manifestly a mere local phenomenon of lunar dawn.

The change from the flat arch to the pointed cone is to be observed in the solar dawn as well; and with the latter, as seen from the mountain, accompanied by overpowering light and brilliant colours, is precisely the feature which used to make the measure-

ment of the "altitude" of twilight very difficult, when not far removed from the time of the sun's appearance.

Considering the lunar phenomenon again with the solar, the cone, if it had been the moon's zodiacal light, ought to have appeared *before* and not *after* the first formation of the twilight arch; and it ought to have been some hundreds of times fainter than when it so appeared, as the lunar representative of the intensely brilliant pink blush preceding the solar day; and yet, as such, it was not much more than barely visible. What then must be the almost inconceivable faintness of the lunar zodiacal light, if it exists in the manner explained on the terrestrial hypothesis, and how many grades must it be below invisibility to all ordinary human vision?

Another remark recent theories appear to require. Even when holding the heliocentric nature of the zodiacal light, some authors speak of it as a "*ring*," with a large interstitial space between it and the sun. The view from Alta Vista was as favourable as any observer ever had for detecting traces of a ring form, contradistinguished to the more generally received opinion of a lenticular mass gradually increasing in density towards the centre, where the sun himself is placed; and I looked particularly to the subject, as one bearing immediately on the recently published dynamic theory of the solar light and heat. The invariable result was, that not the smallest appearance of any traces of the ring form could be made out, but that every thing indicated a mass constantly increasing in density towards the sun. Down to the very horizon, for instance, the intensity of glow continually increased in the axis. This appearance, I may add, is also fully borne testimony to in the diagrams of the Rev. G. JONES.

These diagrams merit a more particular notice, not only because they are the largest printed contribution to our knowledge of the zodiacal light yet made, but because the author has deduced from them new conclusions as to the nature of the phenomenon. The particulars form the third volume of the 'United States Japan Expedition,' and it contains more than 700 quarto pages, of which one-half are engraved plates. Mr. JONES appears to be an honest, zealous, and most persevering observer. "Although," says he, "for six consecutive months, so sick as often to be unable to walk or stand without support, I still kept to my work; and the result, whatever it may be worth, has the merit of one uniform judgment trained by some experience, and stimulated, I know, by deep earnestness in the cause." His eye, too, must be powerful beyond the average of men, for he says, "I could, in clear nights, with the naked eye, easily make out stars of the 6th, and I sometimes thought of the 7th magnitude, through its (the zodiacal light's) densest parts."

In fact, while reading the introduction to the volume, I found everything to admire, until on page xi came this paragraph:—"There is no mention made in any books on the zodiacal light, of any differences in the light itself; but I very soon began to notice that there was a stronger light at the central part, or along the axis: while, beyond this, on either side, and also above, a dimmer kind of light extended itself, as if the matter giving us this light was more condensed at its central parts, and was thinned out beyond."

I cannot but wholly dissent from the opinion expressed above as to the publications

of others than Mr. JONES, and am perhaps not less qualified to do so, as I have long since, both in writing and in engraving, endeavoured to illustrate that same remarkable shading off of the light; and in doing so, gave it not as anything new, but as in the opinion of every astronomer, a leading feature in the appearance of the phenomenon, and a probable explanation of much discordance between different observers.

The shading off is, in fact, so very perfect over the whole extent, and the light, even at its maximum point of intensity, low down in its axis, so faint for human vision, that two different eyes, or two different degrees of transparency of the air on one and the same generally clear night, will entirely alter the apparent boundaries and size of the light. According, too, as the background of the sky may be lit up by moonlight or otherwise, from the smallest appreciable effect, to the maximum degree of the zodiacal light, so will this be seen to shorten from perhaps 60° to 5° or to 0°.

There can in fact hardly be anything more difficult to apply numerical measure to, than definite parts of the zodiacal light; it is like trying to determine the place of a comet from observations of the end of the tail only: and Sir JOHN HERSCHEL's admirable illustrations to his Cape volume, show some striking instances of the apparent alterations in size of HALLEY's comet, according to the amount of twilight illumination of the sky. When such are the natural difficulties of the case, many an observer would leave it altogether, and go to something to which measure can be applied rigidly, as the double stars; but we are not therefore all of us to neglect the zodiacal light. It is an existence in Nature, and if our usual methods of mensuration will not apply to it, we had better improve them.

One of the first elements that seems to be demanded, is some approach to a proof of the elimination of disturbing effects. It is not enough, for instance, for a man honestly to declare what he sees before him; he must understand the weight and effect of all attendant circumstances. When in South Africa, I found a whole season's observations rendered abortive by the presence of the planet Venus very near the zodiacal light, and rejected them accordingly: I cannot therefore understand Mr. JONES's observations with the moon in the same position, as being altogether unexceptionable. Generally, too, in my humble estimation, he hardly attaches sufficient weight to the circumstances that affect the visual and apparent phenomenon; and overlooks that two of the habitudes which he has discovered in the light, and which form the basis of his theory of a terrestrial ring, may be explained in this manner. Thus, that very striking circumstance that he has given of the light being somewhat to the north of the ecliptic when he was in north latitude, and the contrary when he was in south latitude, and which is abundantly borne out by his diagrams as evidenced in the compressed lines of the cone on one side, is accompanied also by this circumstance, that the side so compressed is almost invariably the acute angle with the horizon, where the vapours of the lower atmosphere would infallibly curtail the feeble exterior breadth of that, as compared with the opposite, side of the light.

In his theoretical considerations, again, page xix, Mr. JONES seems to overlook the con-

sequences of the zodiacal light medium, on the heliacal hypothesis, varying in density with its distance from the sun, as is visibly the case with the light; for, given an extreme rarity in our neighbourhood, and much greater comparative density, united with stronger illumination, in the neighbourhood of the sun, there will be hardly any sensible variation in the apparent phenomena seen about the sun from the earth, whether this be, or be not, immersed in the outermost portions. Some very slight symptoms, as I have described already, were given at Alta Vista, of the rare boundaries of the zodiacal light extending beyond the earth's orbit; and Mr. JONES's powerful eye would doubtless have shown them stronger still; but to him would of course have been intensified also the denser part within the orbits of Venus and Mercury; so that the question of the place of the mass of the light would remain where it was.

Towards the end of the American volume, a number of cases of lunar zodiacal light are given; but there again the effects of lunar dawn do not seem to have been fully allowed for; and while feeling the utmost admiration for the Rev. G. JONES, as an honest and most persevering observer, and while recommending to general attention those phenomena of lateral and latitude change which he considers that he has discovered, still I cannot look on his noble volume, but as in the light of a collection of unreduced astronomical observations; and as being therefore not yet altogether arrived at a point, for having theoretical views founded upon it.

(8.) *Lateral Refraction.*

Amongst the instructions communicated to me by the Admiralty were the two following:—

"The observer's attention should be directed to any instance of *lateral* refraction like that remarkable case described by HUMBOLDT as having occurred to him at Orotava."

"Observations to verify HUMBOLDT's remarks on the *lateral* oscillation of stars near the horizon."

These two passages may be assumed to refer to the phenomenon described at pp. 69 and 70 of BOHN's translation of vol. i. of Baron HUMBOLDT's celebrated 'Personal Narrative;' and alluded to again in his still more celebrated 'Cosmos,' vol. iii. SABINE's translation, pp. 55 and 56.

Thence it would appear that, not from Orotava, but from the "Ice cavern," at a height of 11,050 feet, on the Peak of Teneriffe, very shortly after daybreak on June 22nd, 1799, small stars 7 and 8 degrees high, towards the E.N.E., appeared to move about in a variety of abnormal ways, to an extent that was abundantly and even strikingly visible to the naked eye.

The learned Baron suggests that the approach of the sun, still many degrees below the horizon, disturbing the layers of the atmosphere, was the cause of the phenomenon he witnessed. In that case we might expect that the effect should be frequently and widely observable. This is, however, negatived by his own more numerous South American observations, as he himself mentions.

The same result follows from all my trials with the Sheepshanks telescope at Guajara, and the Pattinson equatorial at Alta Vista. At both stations Saturn was frequently observed near the eastern horizon shortly before sunrise, and was invariably found steady and well-defined, remarkably so, considering the circumstances.

No case of mirage, in the sense of violent disturbance of refraction, arising from grand natural causes, was ever seen by us on the mountain; and an exhibition of the sort is hardly to be expected in a breezy locality, almost isolated in the upper regions of the atmosphere. So that when Baron HUMBOLDT mentions, that fluctuations amongst the eastern stars were seen by Prince ADALBERT of Prussia, on the occasion of his ascending the Peak, and standing on the very site of his own remarkable observation, viz. the Ice cavern, one is inclined to ask, if either of those observers eliminated from what he saw, the effects of a vent of hot volcanic air in that immediate neighbourhood?

On my first visit to the Ice cavern, when standing outside in the day time at the usual resting-place, my attention was called by Mr. CARPENTER, son of the Vice-Consul, to the apparent fumes of hot air distorting the rocks, not far off, in the E.N.E. direction from where we stood: and we clearly established, on subsequent visits, that the place must be a passage for volcanic action.

A correction then for these heated breaths, as a local disturbing cause, is essential to any observations of stars made, in their direction, from the "Ice cavern;" and while there is no evidence of the correction having been applied by either party, I am bound to add, after having had my attention directed officially to the matter,—that there are several grave inconsistencies in the accompanying parts of the narrative of the world-famous traveller, which sensibly detract from the importance of the case he has described.

CHAPTER IV.

PHYSICAL OBSERVATIONS.

(1.) *Radiation of the Sun by Thermometers.*

Towards obtaining the radiation of the sun, we were kindly lent by Mr. AIRY two large black-bulb thermometers, having their bulbs enclosed in glass bells, and these furnished each with a syringe for the purpose of extracting the air. This part having been got to work very fairly, the instruments were used against each other, with the idea of one giving the true temperature of radiation, the other the temperature of shade. Each thermometer rested in its own packing box, placed on a short board; so that it might be conveniently tilted against a wall, to an angle of 90° with the incident solar rays, and was as much protected from the wind as possible. The lid of the radiation box was of course always open, while that of the shade box was closed, except when the reading was being made; and to obtain this with the greatest safety, the lid was sawed in two, so that the part covering the bulb never had to be opened at all; while to guard against the radiation penetrating through the lid, two boards were screwed to its upper surface

at a distance of half an inch apart, and had their faces covered with tinfoil. The box was further bored with holes above and below, to allow the circulation of air; but in spite of all these precautions, the shaded thermometer was influenced to about one-tenth to one-fifteenth of the existing radiation; I have therefore found it necessary in the reductions to reduce the shaded black bulb to the true shade temperature, by reference to the observations made more or less frequently with the dry bulb thermometer in the meteorological veranda.

Extensive series of observations were only made at Guajara, as accidents subsequently occurred to the instruments at Alta Vista and Orotava. Some important observations were, however, obtained at the latter stations, which may serve comparative purposes.

Maximum Radiation.

Observations to this end were made at Guajara on July 31, August 1, 3, 4, 5, 7, 8, 9 and 10. Rejecting July 31 and August 7, on account of the violent wind, dust-haze and clouds, we have the following quantities for the radiation, or the excess of the exposed black bulb above the thermometer in the shade:—

	August 1,	at 11 h 48 m A.M.,	radiation $= 102^{\circ}\cdot5$,	temperature $= 67^{\circ}\cdot4$
	August 3,	at 0 31 P.M.,	radiation $= 111\cdot1$,	temperature $= 65\cdot0$
	August 4,	at 9 33 A.M.,	radiation $= 121\cdot3$,	temperature $= 56\cdot0$
	August 5,	at 10 40 A.M.,	radiation $= 120\cdot4 + x$,	temperature $= 57\cdot6$
	August 8,	at 9 14 A.M.,	radiation $= 113\cdot3$,	temperature $= 60\cdot4$
	August 9,	at 9 26 A.M.,	radiation $= 120\cdot0 + x$,	temperature $= 58\cdot0$
	August 10,	at 11 0 A.M.,	radiation $= 116\cdot0 + x$,	temperature $= 62\cdot0$
Mean of 7 obs.	August 6,	at 10 36 A.M.,	radiation $= 114\cdot9 + x \times \frac{3}{4}$,	temperature $= 60\cdot9$

At Orotava, observations on August 27 gave—

At 11 h 33 m A.M., radiation $= 99^{\circ}\cdot8 + x$, temperature $= 78^{\circ}\cdot2$,

and at Alta Vista, observations on September 1 and 2 gave,—

	Sept. 1,	at 8 h 46 m A.M.,	radiation $= 127^{\circ}\cdot8 + x$,	temperature $= 49^{\circ}\cdot2$
	Sept. 2,	at 9 30 A.M.,	radiation $= 127\cdot5 + x$,	temperature $= 49\cdot5$
Mean of 2 obs.	Sept. 1·5,	at 9 8 A.M.,	radiation $= 127\cdot6 + x$,	temperature $= 49\cdot3$

The expression $+x$ used above indicates that the mercury had risen through the whole length of the radiation thermometer-tube 178° or 179°, and was accumulating to an unknown extent in the small bulb which the maker had fortunately constructed there. A third radiation thermometer, kindly procured for us by Dr. LEE, at his expense, without such an upper bulb, was broken from this cause, I am sorry to say, on the first day of observation at Guajara, before we had become aware of the intense force of the direct rays of a mountain sun.

Of the value of x I can form but a very remote idea, perhaps 10° or perhaps 30°. The circumstance of there being such a quantity, while illustrating the powerful radiation of the region, prohibits any attempt at exactitude in the conclusions to be drawn: but we may notice the earlier hour of the day, at which the maximum would seem to take place, as the station is higher, as well as the greater intensity of the radiation: while, that the increase should appear to be nearly as great between Guajara and Alta Vista, as between the sea-level and Guajara, is a circumstance that bears notably on the question of its being practically advantageous to secure for astronomical instruments, heights greater still than any yet experimented on.

Radiation with the Sun on and below the Horizon.

At Guajara the radiation at night was found to be −11°·4, with a temperature of 52°; at sunrise −4°·0, with a temperature of 51°·2; and at sunset +12°·0, with a temperature of 59°·8, for the beginning of August.

That the excessive radiation of the day should heat up the air in the west is not to be wondered at; but that the sun's influence is so weak at rising, that the joint effect of its rays and the general eastern exposure should produce a negative effect, is very remarkable.

The individual observations are as follows:—

Night radiation,	August 1, at 2 h 28 m A.M.,	radiation = − 5°·3,	temperature = 53°·3
Night radiation,	August 4, at 1 43 A.M.,	radiation = −17·4,	temperature = 50·8
Mean . .	August 2, at 2 6 A.M.,	radiation = −11·4,	temperature = 52·0
Sunrise radiation,	August 2, ...	radiation = − 1·9,	temperature = 52·6
Sunrise radiation,	August 4, ...	radiation = − 5·5,	temperature = 47·2
Sunrise radiation,	August 8, ...	radiation = − 5·0,	temperature = 53·8
Mean . .	August 5, ...	radiation = − 4·0,	temperature = 51·2
Sunset radiation,	August 1, ...	radiation = + 6·8,	temperature = 58·8
Sunset radiation,	August 8, ...	radiation = +17·2,	temperature = 60·8
Mean . .	August 5, ...	radiation = +12·0,	temperature = 59·8

Horary Variation of Radiation.

For the purpose of obtaining the march of the radiation through the twenty-four hours, the observations of August 1 and 4 seem safer to be employed than any of the others; the first day having, however, the drawback, that the amount of radiation appears to have been lowered throughout the twenty-four hours, by the violent and unusual wind which was blowing at the time. This effect was strongest about sunrise; but for this period we are enabled to supplement the observations of August 1 by those of August 4, which appears to have been an unexceptionable day. As usual on such days, the mercury mounted soon after 9 A.M. above the graduation of the thermometer.

Obtaining, however, the ratio of the true radiation of August 4, and the wind-lowered radiation of August 1, during the period common to both, and applying it throughout, we have for the latter day the following tabular view of the progress of radiation + and — through the twenty-four hours, at the height of 8903 feet above the sea-level.

Radiation at Guajara on August 1, corrected.

Date.		Radiation.	Temp.	Date.		Radiation.	Temp.	Date.		Radiation.	Temp.
	h m	°	°		h m	°	°		h m	°	°
Aug. 1.	4 43 A.M.	— 5·8	47	Aug. 1.	1 13 P.M.	+ 123·4	60	Aug. 1.	9 43 P.M.	— 6·3	49
	4 58 A.M.	— 5·6	47		1 28 P.M.	119·4	61		9 58 P.M.	6·1	50
At 5h 10m Sunrise					1 43 P.M.	123·1	61		10 13 P.M.	6·7	50
	5 13 A.M.	— 3·0	47		1 58 P.M.	123·4	60		10 28 P.M.	5·8	49
	5 28 A.M.	+ 7·0	47		2 13 P.M.	119·2	60		10 43 P.M.	6·3	49
	5 43 A.M.	30·5	48		2 28 P.M.	121·2	60		10 58 P.M.	6·4	49
	5 58 A.M.	49·0	48		2 43 P.M.	116·7	59		11 13 P.M.	6·0	48
	6 13 A.M.	63·0	49		2 58 P.M.	112·3	60		11 28 P.M.	6·0	48
	6 28 A.M.	73·0	49		3 13 P.M.	112·3	59		11 43 P.M.	6·4	48
	6 43 A.M.	81·0	50		3 28 P.M.	110·7	59		11 58 P.M.	6·1	48
	6 58 A.M.	88·0	50		3 43 P.M.	112·6	58	Aug. 2.	0 13 A.M.	6·0	48
	7 13 A.M.	96·5	51		3 58 P.M.	109·5	59		0 28 A.M.	5·7	48
	7 28 A.M.	99·0	51		4 13 P.M.	108·9	58		0 43 A.M.	4·7	48
	7 43 A.M.	101·0	52		4 28 P.M.	103·2	58		0 58 A.M.	5·7	48
	7 58 A.M.	103·0	52		4 43 P.M.	98·1	57		1 13 A.M.	5·7	48
	8 13 A.M.	106·5	53		4 58 P.M.	93·6	56		1 28 A.M.	5·5	48
	8 28 A.M.	109·0	54		5 13 P.M.	104·8	56		1 43 A.M.	5·5	48
	8 43 A.M.	113·0	54		5 28 P.M.	104·7	55		1 58 A.M.	6·6	48
	8 58 A.M.	116·1	55		5 43 P.M.	100·0	55		2 13 A.M.	5·4	48
	9 13 A.M.	117·5	55		5 58 P.M.	93·0	54		2 28 A.M.	8·9	48
	9 28 A.M.	119·0	56		6 13 P.M.	70·6	54		2 43 A.M.	5·8	48
	9 43 A.M.	121·0	56		6 28 P.M.	46·9	53		2 58 A.M.	5·8	48
	9 58 A.M.	124·2	57		6 43 P.M.	15·9	53		3 13 A.M.	5·2	48
	10 13 A.M.	125·2	57	At 6h 49m Sunset					3 28 A.M.	5·1	48
	10 28 A.M.	121·2	58		6 58 P.M.	+ 3·7	52		3 43 A.M.	4·3	48
	10 43 A.M.	120·0	59		7 13 P.M.	— 1·5	51		3 58 A.M.	4·5	48
	10 58 A.M.	124·0	59		7 28 P.M.	3·9	51		4 13 A.M.	5·4	48
	11 13 A.M.	123·9	59		7 43 P.M.	6·7	51		4 28 A.M.	3·7	48
	11 28 A.M.	144·0	59		7 58 P.M.	6·7	51		4 43 A.M.	3·4	48
	11 43 A.M.	152·2	59		8 13 P.M.	6·4	51		4 58 A.M.	3·3	48
	11 58 A.M.	152·4	60		8 28 P.M.	6·4	50	At 5h 11m Sunrise			
	0 13 P.M.	146·4	60		8 43 P.M.	7·3	50		5 13 A.M.	— 2·0	47
	0 28 P.M.	139·8	60		8 58 P.M.	6·3	50		5 28 A.M.	+ 1·7	48
	0 43 P.M.	132·1	60		9 13 P.M.	6·1	50		5 43 A.M.	22·5	48
	0 58 P.M.	+ 130·2	60		9 28 P.M.	— 6·0	49		5 58 A.M.	+ 43·0	48

With both temperature and radiation in the preceding Table, the object has been to exhibit what takes place on the most favourable day, not to take a mean of a number of days, good and bad; a plan which, however proper for the meteorology of the mountain, is not suitable to an inquiry into the heating power of the sun. There would have been advantage, doubtless, in taking a mean of a number of equally favourable days, if they could be had, partly to eliminate errors of observation, partly to eliminate the little varying asperities in the radiation curve, produced by natural influences: taking the quantities, however, as they stand, we may derive from them some useful hints for ulterior proceedings; as thus, that the next black-bulb thermometer prepared

for observation on a high mountain should be graduated to above 212°, such a temperature of radiation having been reached on Guajara in the middle of the day.

Towards the chief astronomical end of the Expedition, there is yet a more interesting conclusion to be drawn. The days of highest radiation are those of least temperature, and *vice versâ*; and this difference obtains in a signal degree on days when there was no visible disturbing action of wind or clouds. What then causes the radiation of one day to be greater than that of another, and the temperature less? The immediate agent appears to be the atmospheric dust, which has already been spoken of in the Astronomical Journal as so prejudicial a medium to telescopic vision, weakening direct light and multiplying general light; acting, in fact, by light precisely as the measures of radiation and temperature prove that it does by heat.

Hence, then, we may easily understand why, with the dust strata rising to a very limited height, say 11,000 feet, the small difference of altitude between Alta Vista and Guajara produced as great an increase in the radiation as did the great difference, nearly four times as great, between Guajara and Orotava. Hence also we are furnished with a very portable apparatus for ascertaining on a high and distant mountain the principal elements that produce a good astronomical site.

(2.) *Radiation by Actinometer.*

In the accurate determination of solar radiation for physical inquiries, the black-bulb must yield to Sir John Herschel's actinometer. That, in principle, has been stated by an able judge to be perfect; but the instruments themselves, as furnished by the best maker in 1856, according to our Teneriffe experiences, have not arrived at equal practical perfection. One of the most improved, the only one procurable at the time we left England, was very kindly lent by Mr. Airy, and with great generosity he ordered another to be constructed by the same artist as quickly as possible, and sent after us. Of these two, the internal thermometer of the first, when unpacked on Guajara, was found broken, and the actinometer-bulb had leaked, under circumstances of carriage, where barometers, thermometers, and even the gold leaves of an electrometer, and the silk fibre of a thermo-multiplier, travelled with perfect safety: the second actinometer, only arriving in Teneriffe at the conclusion of the summer, never got beyond the Consul's office in Santa Cruz; nevertheless—though admirably packed, first in its own box, and then with this placed in the centre of a much larger box, and filled in on every side with paper shavings—it had leaked, and to such an extent, that the fluid could not be brought into the graduated tube. No additional stock of fluid, and no solid materials for preparing it with water, had been supplied with either instrument. I mention these things only as indications of improvements to be made on the next occasion.

Trying to make up for the broken internal thermometer of the first actinometer on Guajara, by placing a small one, wrapped up in blue calico, under the glass covering the great blue bulb, I began to make observations on August 7; they were continued throughout the day, except during a cloudy interval. Wind and haze much interfered

with the results. August 8, however, opened more auspiciously, and I began before sunrise; and with the assistance of the mate and carpenter of the yacht, kept up observations continuously throughout the day, until the leaking of the bulb (which had begun again in the middle of the day, apparently from some effect of the heat twisting the wood, and finally splitting the glass) increased to such an extent, that the graduated tube could no longer be kept full.

Considering the state of the instrument, the only purpose that the observations can be made useful for, is to institute a rude comparison with the results of the black-bulb thermometers, which were simultaneously observed throughout the day. To facilitate this purpose, the actinometer results in the following Table have been multiplied by a factor, such as was found by trial, to make the sum of its degrees or divisions throughout the day, equal to the sum of the thermometer degrees. Each actinometer reading in the Table is the result of four "suns" and three "shades," corrected for temperature by the reading of the small inserted thermometer, and the Table given by Sir J. HERSCHEL in the 'Admiralty Manual.' Each black-bulb reading is the result of a pair of readings before and a pair immediately after each group of actinometer observations.

Comparison of Actinometer and Black-bulb results for Solar Radiation on August 8, on Guajara.

Time.	Actinometer radiation.	Black-bulb radiation.	Time.	Actinometer radiation.	Black-bulb radiation.	Time.	Actinometer radiation.	Black-bulb radiation.
h m	d	°	h m	d	°	h m	d	°
5 10 A.M.	− 1·8	− 2·8	9 6 A.M.	+88·2	+100·0	1 30 P.M.	+85·1	+71·0
5 14 A.M.	Sun rose.		9 28 A.M.	83·3	100·2	1 54 P.M.	85·1	80·8
5 32 A.M.	+22·5	+ 5·4	9 44 A.M.	85·0	99·0	2 24 P.M.	89·9	81·8
5 48 A.M.	36·3	26·8	10 0 A.M.	84·6	99·3	2 54 P.M.	84·2	76·0
6 10 A.M.	56·7	52·1	10 14 A.M.	84·2	98·2	3 24 P.M.	76·6	72·4
6 24 A.M.	59·8	61·2	10 34 A.M.	81·1	98·4	3 44 P.M.	83·7	71·9
6 40 A.M.	63·3	69·2	10 54 A.M.	78·8	93·7	4 0 P.M.	81·5	71·9
7 4 A.M.	68·7	57·6	11 14 A.M.	79·3	89·2	4 14 P.M.	71·8	70·4
7 20 A.M.	74·4	72·2	11 30 A.M.	74·4	87·0	4 32 P.M.	77·0	67·9
7 34 A.M.	77·1	79·0	11 44 A.M.	72·6	87·4	4 46 P.M.	75·3	64·5
7 56 A.M.	81·1	84·8	0 10 P.M.	94·4	87·0	5 4 P.M.	62·0	62·6
8 18 A.M.	82·8	88·0	0 34 P.M.	93·5	82·9	5 20 P.M.	63·3	58·3
8 32 A.M.	85·9	88·0	0 54 P.M.	79·7	74·0	5 44 P.M.	+54·5	+46·6
8 48 A.M.	+85·4	+95·6	1 14 P.M.	+84·2	+ 72·0		Actinometer broke down.	

Much as might be expected from the principle of the actinometer, it approved itself at sunrise as the more sensitive instrument; but the cause of the differences between the two instruments through the middle of the day is not equally plain; neither of them follows the law of altitude, and their differences from each other are far beyond errors of observation.

(3.) *Radiation of the Moon.*

For the particulars of observations with the excellent thermo-multiplier kindly lent by Mr. GASSIOT, reference may be made to volume 1, where the whole of them are entered, with notes of all attendant circumstances. Here it may suffice to state the resulting mean quantities.

On August 15th, the night of the full moon, the altitude of the moon being 42°, three readings of the needle with the cone of the battery turned towards the moon, compared with three readings before and three readings after, when the cone had been turned in azimuth about 20° east of the moon, gave a heat effect for the moon :—

Sidereal time. h m		°
At 21	11 . . .	+1·0
At 21	17 . . .	+0·1
At 21	20 . . .	+1·9
At 21	24 . . .	+0·2
At 21	27 . . .	+0·3
At 21	31 . . .	+0·2
At 21	35 . . .	+0·6
At 21	37 . . .	+0·7
At 21	44 . . .	+0·1
At 21	46 . . .	+0·5
Mean of ten groups, each group consisting of nine observations . . .		+0·56

Then comparing the moon readings with readings west as well as east, before and after, the following results were obtained :—

Sidereal time. h m		°
At 21	48 . . .	+0·3
At 21	50 . . .	+0·5
At 21	52 . . .	+0·3
At 21	54 . . .	+0·3*
At 21	56 . . .	+0·2
At 22	1 . . .	+0·1
At 22	3 . . .	+0·1
At 22	5 . . .	+0·2
At 22	7 . . .	+0·1
At 22	9 . . .	+0·2
At 22	11 . . .	+0·2
At 22	13 . . .	+0·5
Mean of twelve groups		+0·25

Placing one of PRICE's candles (for his emigrant's ship lantern) in a square tin lantern, blacked inside, with the door open, on a tripod at a distance of 14 feet 9 inches from the thermo-multiplier, and taking exactly as in the case of the moon, groups of readings for east of the candle, the candle, and west of the candle, the following results were obtained for the heat of the latter :—

	h m	
At	22 27	. . . . +0·9
At	22 29	. . . . +0·5
At	22 31	. . . . +0·9
Mean of three groups, including twenty-one readings		. . . +0·77

My naked hand, held at a distance of 3 feet, produced about + 7°·0,
and at a distance of about 3 inches, produced about . . +20·0.

Again, on August 16th, or the day after full moon, and with that luminary at a height of 49°, the comparison of similar groups to those of the previous night gave,—

	h m	Moon's heat.
At	22 43	. . . . +0°·2
At	22 45	. . . . +0·3
At	22 54	. . . . +0·2
At	22 56	. . . . +0·6
At	22 58	. . . . +0·5
At	23 0	. . . . +1·9
At	23 2	. . . . 0·0
At	23 14	. . . . −0·1
At	23 16	. . . . +0·2
At	23 18	. . . . +0·8
At	23 20	. . . . +0·2
Mean of eleven groups		. . . . +0·44

The hand held at a distance of 18 inches in front of the cone, produced at $23^h\ 27^m$ a heat effect of +9°·0.

The "hand" observation of each night was rude, and merely to be sure of the sign accompanying heat; but the candle observations were made as carefully and accurately as possible; and as PRICE's candles appear to be very uniform in quality, it is possible that the value of the degrees of the thermo-multiplier may be accurately obtained in terms of FAHRENHEIT by further observations in this country. We shall then be able to state the moon's radiation in similar terms to the sun's. That the moon's radiation was fully sensible, the above observations will I think abundantly show; the only doubt is the respective weights to be given to the different series. The observations of the 16th having been affected by wind, and the first series on the 15th having been one-sided, I am inclined to weight them as follows:—

$$15^1=2,\ 15^2=4,\ \text{and}\ 16=1.$$

The simple arithmetical mean is, for the

Moon at 45° high . . . . . Radiation $=+0°{\cdot}42$
When corrected for the weights it becomes . $=+0°{\cdot}37$

Sir JOHN HERSCHEL has explained the inability of observers at low levels to obtain heat indications of the moon's rays, by considering that the heat is spent in dissipating vapours in the upper regions of the atmosphere, and so explains the preponderance of clear over cloudy nights at the time of full moon. On Guajara, there appeared to be a strong tendency to "upper" clouds during the several days preceding full moon, but on that night every particle of them disappeared; the lower clouds, however, were constant through the whole lunation. This does seem to confirm Sir JOHN's idea; and to show too, that the moon's heat, though effective at great heights, is entirely expended before arriving at the lowest strata of cloud, 2300 feet above the sea. The elevation of the upper clouds which were apparently so effectually acted on, we had no means of accurately judging of, but I should suspect that it could not have been less than 15,000 feet; at that height then, or higher, should be made the next observations on the radiation of the moon.

(4.) *Lines in the Spectrum.*

Towards observing the black lines in the solar spectrum, we had a speculum to reflect sunlight, kindly furnished by Mr. J. NASMYTH, C.E., and an apparatus consisting of a prism, a fine adjustable slit placed in the focus of a 2-inch object-glass, and a telescope of the same size, with magnifying powers as high as 30, prepared for, and lent to us, by Mr. AIRY. There was no angular measurement contemplated; only eye observation, and comparison of differences between the spectrum seen, and that engraved by FRAUNHOFER. To employ these instruments on Guajara, a small chamber, some 10 feet square, was built of rude stone, roofed in with planks and old canvas, and further covered with a quantity of "*retama*" branches to keep out every particle of the sun's light: while a square tube of wood, 5 feet long, with a moderate aperture at the end, was thrust through the wall in the direction of the speculum mounted on a small stone pier outside. In this manner a considerable degree of darkness was secured, even when the sun's rays were being reflected into the instrument.

A cursory examination of the spectrum showed much general correspondence with FRAUNHOFER's view as to the principal lines; but so great discordance as to detail, that I thought it better to proceed on an entirely independent footing, and make original drawings of what I saw; and when well satisfied with them, to compare them with the engraving. One evening trying the sun unusually low, and finding new features worth following up further than could be done while using the reflected ray from the speculum, I took the prism apparatus out into the open air, and by means of a theodolite stand and photographic black bag, was enabled to continue the observations until the sun set at the usual mountain zenith distance of 91° 11′. These direct observations of the sun were repeated on many occasions with the sun both east and west. The lunar spectrum and that of the blue sky were also similarly examined.

So far for the Guajara experiences. At Alta Vista a similar optical dark room was prepared; but profiting by hints procured from the *direct* use of the line instrument at

low altitudes, I tried it on the sun at mid-day in the same manner; when an immense increase in the number and definition of the black lines at the violet end took place. With the reflected ray, the two bars of H could but just be discerned as faint nebulous streaks, B, C, and D being as sharp and as black as silver wires in a telescope; with the direct ray the individual lines composing the bars of H could be distinctly separated, and many lines appeared indistinctly in the space beyond. The conclusion thence to be derived was, unfortunately, that our particular speculum did not reflect the violet end of the spectrum; and our observations were therefore not comparable in that part, even if they were in others, with standard observations elsewhere. The discovery was made too late to enable a *direct* determination to be made for Guajara, but the method was employed for Orotava when we returned there from the mountain a few days after.

Red End of the Solar Spectrum.

In the accompanying Table (Plate XXXV.) are arranged the whole of the drawings of the red end of the spectrums that were taken at the three stations, on the same scale as FRAUNHOFER'S justly celebrated Munich engraving. The times and circumstances of the observations being appended, will enable any one to judge of the reality of the facts purporting there to be represented.

Bearing in mind that great accuracy of position is not pretended, and that though much care was bestowed on the general appearance, thickness, and definition of the lines, the shortness of the time available was entirely inadequate to procuring a good drawing, and that several of the diagrams should be employed together in deducing a result,—we may proceed to the examination. Comparing the eleven Teneriffe spectrums of the sun with FRAUNHOFER'S, we can only assume identity in place of the lines A, *a*, B, C, D, E, and *b*: everything else appears differently. Of this difference the prevailing feature appears to be, that whereas FRAUNHOFER'S spectrum stretches to beyond A, which is seen by him as a clear and distinct line,—he gives none of the numerous broad bands and groups of lines between A and *a*, and *a* and B, that were visible on the mountain and below, whenever A was quite or nearly visible.

From the fact of FRAUNHOFER'S spectrum including A, we might be entitled to expect from the Teneriffe observations, that it represents the sunset appearance (see No. 10); but then how can the omission of the broad bands of lines between A and B, and C and D, and especially those beyond D, be explained? If, on the contrary, the absence of those marked bands is to be regarded as a proof that a high spectrum was intended, Nos. 1, 2, and 3 indicate that A should not be seen in such a position. Again, while the spaces between A*a* and *a*B are blank in FRAUNHOFER, and well filled in Teneriffe, he has some lines between B and C, a compartment always remarkably empty with us.

Comparing the Teneriffe observations *inter se*, we may assume 2 and 3 as giving a near approach to a zenith solar spectrum, and 4, 5, 6, 7, 8, 9, 10 as giving the effects superinduced by the sun being seen through a greater thickness of the atmosphere by

lowering in altitude only, all the observations being made at the same station, viz. Guajara at a height of 8903 feet.

A zenith spectrum then, at that height and with the particular apparatus employed, would appear to begin between *a* and B; and, excepting the lines C and D, to have nothing noticeable between B and E. A horizontal spectrum, on the other hand, station and instrument remaining the same, begins outside A, has numerous powerful bands of lines between A and B, but none between B and C; and while C has not increased in thickness, B has more than quadrupled its size, maintaining full sharpness and definition. Again, a certain excessively fine line, at the distance of B to C beyond C, has grown to many times the thickness of the latter, and is accompanied by a broad and marked band of finer lines. A more extensive increase still is perceived in the innumerable lines between C and D, and immediately beyond D. Of these variations from a zenith spectrum, as observed phenomena, there is no doubt; for the series of drawings, taken quite independently, are found on being now brought together, to confirm each other in the result of the growth of these lines with the zenith distance. The observations of August 9 are the most important to this end: there were three drawings obtained the same evening, and the lines grew visibly under my eyes: the red end *apparently* lengthened out from B to A; additional lines were seen every succeeding moment, and the old ones became better defined, causing nebulous bands at 85° zenith distance to become groups of fine black lines at 91° zenith distance. Looking at the same time to the notes of colour, the red *seems* continually to have grown, to the final exclusion, at 91° zenith distance, of yellow as a pure colour, orange merging at once into green.

Contrasting now No. 1 with Nos. 2 and 3, we find, if we may overlook the two latter having been observed by reflected, instead of direct rays, that a zenith spectrum at the sea-level differs most notably from one on the mountain, by the greater extent of the red end visible, and by the increased number of lines; and that, though it shows some approximation to a low-sun mountain spectrum, it has some radical differences therefrom.

Professor STOKES indeed suggests, that the deficiency of the red end of my high-sun mountain spectra may be due to the more luminous rays extinguishing the faint red; and that if the former had been absorbed by a cobalt-blue glass, or the extreme red separated by refraction through a second prism, A might have been seen; just as in fact it was seen with the low-sun spectra, when the atmosphere acted the part of a suitable absorbing medium; and the suggestion is of extreme value for future experiments, though it is proper to state, that on Teneriffe the magnifying power employed was such, as necessarily to throw the brightest part of the spectrum out of the field of view when the extreme red was under examination.

Red End of Sky Spectrum.

No. 13 appears to show that a zenith sky spectrum on the mountain with the sun in

the neighbourhood, does not differ much from the solar spectrum; but Nos. 14, 15, and 16 show that such a spectrum, with the sun somewhat low, as 20°, has neither lines nor light at the red end, but that they gradually increase as we try the lower regions of the sky, showing there the remarkable multitude of lines beyond D.

Taking together the whole of the sky spectrums, 12 to 17, and comparing them with those of the sun, we find that C is not marked in circumstances where it might be expected; and when it does appear, it is overpowered by the "growing" line in the direction of D. Likewise D is overpowered by the numerous broad bands beyond it; so that when the spectrum is seen faintly, those variable lines might easily be mistaken for C and D, and a greater degree of identity might thence be considered to prevail between the sun and sky spectrums than actually obtains.

Red Ends of Lunar Spectrums.

The moon was not well situated for spectrum observations, though drawings were obtained on August 13th and 15th, at altitudes of 25° and 38°; and at times, two days before, and on the night of, the full moon.

The most striking feature was the blood-red character of the red end; beyond the extreme intensity of this colour, the other tints had nothing notably different from a sun spectrum. Notwithstanding the amount of red light, no lines could be perceived there: in this circumstance was a striking difference to the low sun spectrums, where, as the red became predominant, the number, size and visibility of the lines in the red increased also. The first line identified in advancing from the red end, was the growing line between C and D; from thence was a long blank space until three fine lines near E were seen, then E and F. These observations were direct.

Violet End of the Spectrum.

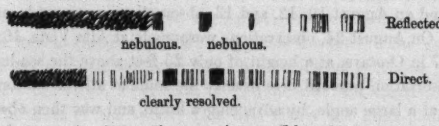
Eight drawings of the violet end of the sun's spectrum, two of the sky's, and two of the moon's were obtained; but I do not think them worth engraving here, as most of them labour under the untoward effects of the speculum. It may suffice to remark, that at Guajara, the vertical sun spectrum terminated beyond H, while the horizontal sun spectrum was so shortened at that end as to terminate between H and G.

Again, comparing a high sun spectrum at the sea-level with a similar one at Alta Vista, 10,702 feet high, both observed direct, it was found that while in the former the spectrum terminated immediately beyond H, and the two bars of H were nebulous, in the latter the spectrum extended beyond H to three times the distance of its bars asunder: the two said bars also lost all their nebulosity, being clearly resolved into their component lines; many fine clear lines were seen between them, and many appeared nebulously in the space beyond. In the sky spectrums, and more particularly in those of the moon, the prominence of G was remarkable; next came F, while H was nearly if not quite invisible.

(5.) STOKES's *Spectrum.*

At Guajara many experiments were made in the dark optical room with a quartz train, lent by Professor STOKES, but they are all unfortunately faulty, by reason of the speculum employed.

Of two large drawings that were made on August 10 and 12, near noon, one terminates at the limiting line in a drawing of the extended spectrum furnished to me by Professor STOKES, the other contains two lines more. What would have been the result had the direct solar light been employed, may be gathered from the two subjoined drawings of the violet end of the ordinary spectrum, as seen with the glass apparatus at Alta Vista: they were taken on the same day, September 12, and within a short time of each other.



The mean, then, of the observations on August 10 and 12 shows that a little more of STOKES's new portion was seen on the mountain than has been seen near the sea-level, notwithstanding the drawback of the speculum; while if we add for that, what we are fairly entitled to do from the two above views of H, direct and reflected—we may assume that there is a much greater amount of the more refrangible rays in the sun's light in the upper, than in the lower regions of the atmosphere.

This result is confirmed by another observation. The spectrum formed by the quartz train was frequently photographed on a collodion plate, and the image so formed was found identical with that presented to the eye by uranium glass. Taking then powerful photographic effects as an indication of the abundance of rays of high refrangibility, it is very remarkable to find, on looking over my landscape photographs, about 120 in number, and pretty nearly equally divided between the three stations, Orotava, Guajara, and Alta Vista, that not only is there always a greater intensity, but that the distances came out invariably much better, in proportion as the station is higher.

At the height of 10,702 feet, the eastern wall of the crater of elevation, distant some four miles, is given with all the detail that the eye could appreciate at the time; while at the sea-level on the finest mornings, and when the cliffs above Realejo, not three miles distant, were vividly illuminated by the morning sun, and casting on one side dense and dark shadows—yet the photographs would persist in giving nothing but the mass of the mountain in one uniform tint, save only one remarkably white stratum. This at least testifies to the focus having been exact; while the detail of things in the foreground is represented with such vigour, as to prove that the quality of the photographic material was by no means deficient.

In place of showing the mountain with all the intense detail brought out to the eye by the sun shining strongly on its rocky slopes, the appearance was rather as if that luminary were on the other side, and we only saw the shaded form of the ridge. Or

it might be likened to the effect that would have taken place to the eye, had the mountain been seen through a much greater depth of atmosphere, or had that atmosphere been thicker, as with a diffusion of smoke throughout it.

(6.) *Magnetometer.*

For the purpose of obtaining observations of magnetic intensity, a vibrating needle was kindly supplied by Mr. AIRY, together with some fine aloe fibres, procured by himself in Madeira. On opening the boxes at Guajara in the beginning of August, at which time most of our instruments were suffering from the extreme drought, the mahogany stand was found to have so shrunk on the thick plate-glass cover of the needle area, as to fix it in completely. By cutting away the wood, however, around the glass, it was got out, and on August 10, 12, and 13, observations were made at that station, 8903 feet high. On August 24, observations were made at Alta Vista, 10,702 feet high, and on August 27 in Orotava, at a height of only 25 feet above the sea-level.

The plan of observation pursued, was exactly the same at all the stations: the needle was set swinging at a large angle, by advancing a knife, and was then observed at every tenth vibration, through 300 vibrations; the mean angle of a series was always near 45°; and a correction has been since applied to reduce the readings exactly to that angle. The times were observed by a sidereal chronometer.

Magnetometer.

No.	Date.	Locality general.	Locality particular.	Mean of thirty observations of ten seconds each.	Mean for each station.
	h m			sec.	
1	Aug. 11, 4 10 P.M.	Guajara	On a pedestal of the trachyte stone of the hill, and under the shade thrown by a deal plank	38·02	s. 38·04
2	Aug. 11, 4 46 P.M.	Guajara	Ditto	38·05	
3	Aug. 12, 5 40 A.M.	Guajara	Ditto	37·91	
4	Aug. 12, 6 10 A.M.	Guajara	Ditto	37·90	
5	Aug. 13, 9 0 A.M.	Guajara ..... Altitude= 8,903 feet	Ditto	38·31	
6	Aug. 24, 10 30 A.M.	Alta Vista	In shade of large block of black lava, N.E. of station	37·72	38·45
7	Aug. 24, 11 25 A.M.	Alta Vista	In shade of lava stream, to S. of station	39·05	
8	Aug. 24, 3 20 P.M.	Alta Vista ..... Altitude=10,702 feet	In empty room in station	38·58	
9	Aug. 27, 8 0 A.M.	Orotava	Basalt step of Inn yard...	37·54	37·73
10	Aug. 28, 7 35 A.M.	Orotava	Basalt step of Inn yard	37·67	
11	Aug. 28, 8 20 A.M.	Orotava ..... Altitude= 25 feet	Centre of Inn yard	37·99	

It is satisfactory to find the means of all the observations at each station giving a continually increasing time of vibration with the altitude, but I do not attach importance to the result, because,—1st, a difference far exceeding the whole effect of height appears to have been caused at Alta Vista by change of position in the instrument with reference

to the lava streams; and 2ndly, the rocks at the several stations were found to be slightly magnetic in hand specimens; the most powerful of them was one from Guajara, consisting of obsidian and trachyte in alternate laminæ: the origin of the specimen was a small crater about 100 feet below the station, and the material was present there in large masses.

(7.) *Polarimeter.*

A polarimeter, devised by Mr. AIRY, constructed and kindly lent by him for the Teneriffe experiments, was employed frequently; but not, I find now, and am sorry to say, with so much discrimination as would have been advisable.

The instrument consists of a principal tube, capable of being turned round its own axis, and of being pointed in any direction, its angular distance from the sun being given by a shade-bar on a graduated semicircle; this semicircle being mounted on a collar, which is free to turn, or can be clamped on the tube. The light which passes down from the sky through the tube falls on a bundle of reflecting glass plates, supported just under the tube's lower end, on a transverse axis, carried by two arms projecting from the sides of the tube. This axis allows the glass plates to have their inclination varied at pleasure, with reference to the tube's incident light, and has connected with it a mechanism, by which an eyepiece, armed with a NICOL'S prism and plate of calc-spar, is always carried in the direction of the reflected light; graduated arcs being added at the side, for reading off the angles of incidence and reflexion.

Now with this apparatus, when its eyepiece is at the angle of complete polarization, the polarization produced by the glass plates is necessarily shown, and the corresponding coloured rings exhibited; but at angles of such imperfect polarization, that their diminution of the coefficient of etherial vibrations in one plane, is only equal to the atmospheric diminution of the coefficient of vibrations in the transverse plane, all traces of polarization disappear. Beyond those angles, of course, the complementary rings due to the polarization of the atmosphere or blue sky are seen.

The practical method of observing was therefore, starting from a mean angular position of the eyepiece, giving great intensity of glass-plate polarization, slowly to decrease the angle between incidence and reflexion, until the vanishing point of the rings, or the passage of the one set into the other, was just arrived at: the readings being then noted, the angle was again opened out, past the maximum of glass-plate polarization, until the vanishing point on the other side was arrived at, and duly read off on the graduated arcs; when half the angular distance between the two vanishing points was set down as "inverse intensity of sky polarization."

It is here supposed that the instrument was previously adjusted, by turning the tube round its axis, so that the plane of reflexion was perpendicular to the plane of sky polarization, which was ordinarily assumed to pass through the sun; but the instrument itself is competent to point out whether this adjustment be made, since otherwise the rings do not wholly vanish at any incidence.

When the tube was pointed to within 20° of the sun, or its opposite point, the sky polarization was so weak, that the rings due to the polarization of the glass plates were

never lost sight of through the whole extent of angular motion possible to the eyepiece and its carrying bar, about 130°; and the results therefore, for that region, must be negative. But for greater solar distances, reckoning from the equator of a sphere having the sun in one of its poles, or in terms of "sky declination," we have the following results at the three stations noted.

Polarimeter.

Guajara.				Alta Vista.				Edinburgh.			
Date.	No. of obs.	Sky decl.	Inverse intensity of sky polaris[n].	Date.	No. of obs.	Sky decl.	Inverse intensity of sky polaris[n].	Date.	No. of obs.	Sky decl.	Inverse intensity of sky polaris[n].
1856. Aug. 14.	1	1°	52°·1	1856. Aug. 23 to Sept. 11.	10	1°·2	23°·6	1857. Oct. 30.	4	0°·0	20°·8
	1	4	41·0		10	3·7	24·6		6	5·0	20·2
	1	6	42·0		10	5·7	26·4		4	12·5	22·9
	1	9	41·5		10	7·7	25·6		2	22·5	28·0
Exceptional day, abnormal local cloud suspended over station.					10	10·2	26·8	Nov. 19.	12	0·0	33·4
					10	13·8	28·0		4	5·0	34·8
Aug. 16.	10	3·8	28·4		10	16·0	27·6		4	10·0	37·2
	10	10·1	25·6		10	19·9	30·7		3	15·0	38·9
	10	13·3	27·7		10	23·5	32·2		5	25·0	37·8
	10	18·1	32·2		10	26·2	33·3	Sky clear from clouds, air calm, but filled with smoke.			
	10	26·1	36·2		10	28·5	35·7				
	10	33·8	43·0		10	32·8	40·6				
	10	40·5	49·7		10	36·3	43·0	Nov. 20.	4	0	21·1
	10	46·7	54·2		10	40·1	46·0		4	5	21·8
	5	56·8	63·9		10	45·0	50·2		5	9	22·3
					10	49·5	56·4		2	15	23·2
					10	53·8	59·1	Nov. 24.	2	0	21·2
					10	59·6	63·2		2	5	21·5
									2	10	22·2
									1	15	23·1

Before comparing the above observations, we must reject the Guajara series of August 14, as vitiated by an unusual local cloud; and the Edinburgh series of November 19, on account of the evidently prejudicial effect of smoke nearly uniformly diffused in all the upper air. To test this point still further, the following series for intensity in the sky equator was taken, everything remaining the same but the altitude of the principal tube; and when this was directed at 10° to the strongly smoky band on the horizon, there was evidently a sudden decrease of the intensity of the polarization, shown as before by an increase of the instrumental numbers:—

Altitude 45°, inverse intensity of sky polarization = 31°·7
Altitude 20, inverse intensity of sky polarization = 32·3
Altitude 15, inverse intensity of sky polarization = 32·9
Altitude 10, inverse intensity of sky polarization = 41·0

Comparing then the three normal Edinburgh days with the mean of the whole Alta Vista period, the polarization would appear to be rather stronger below than above, but at either station to follow the law of maximum intensity at or near 90°.

The next step is a more delicate one, namely, to compare the intensity in declinations towards, and from, the sun. For this purpose, of the three normal Edinburgh days, October 30 may be taken by itself, and the two shorter series on November 20 and 24 may be taken together; we then have two series, both indicating the maximum of polarization in about 98° of sun polar distance, thus—

October 30.			November 20 and 24.		
Sun. Polar dist.	No. of observations.	Inverse intensity of sky polarization.	Sun. Polar dist.	No. of observations.	Inverse intensity of sky polarization.
75°	1	26°·0	°		°
80	1	24·5	80	3	23·5
85	1	20·5	85	3	21·6
90	2	20·5	90	6	21·1
95	3	19·8	95	3	21·7
100	1	20·5	100	3	21·7
105	1	20·5	105	3	28·1
110	1	25·0			
115	1	26·0			

At Alta Vista the observations of September 10 appear most suitable for this purpose, and give a maximum intensity about 82° distance from the sun, thus—

Sun. Polar dist.	No. of observations.	Inverse intensity of sky polarization.
64°·0	26	30°·1
70·0	27	26·1
80·5	27	26·2
85·0	21	25·1
91·7	25	28·8
100·8	25	29·6

A series was also taken at Alta Vista on September 10 and 11, to try the intensity in different planes, the normal plane employed, designated on the instrument by 90°, being when the eye-piece moved in a plane at right angles to the sun-shade plane.

Plane employed.	No. of observations.	Inverse intensity of sky polarization.
−82°·5	18	28°·5
−85·0	18	27·3
−87·5	18	26·3
90·0	17	26·7
+87·5	19	26·8
+85·0	19	27·1
+82·5	18	28·4

These observations may be taken as establishing 90° as the true plane; nine observations in Edinburgh on October 30, gave no effect from +80° to −80° at all equal to the error of observation, which appeared to increase with the distance from 90°.

The plane was also attempted to be ascertained from the estimated amount of rotation

observed in the passage of the black into the white cross, both at Alta Vista and at Edinburgh.

Alta Vista.			Edinburgh.		
Plane.	No. of observations.	Amount of rotation.	Plane.	No. of observations.	Amount of rotation.
°		°	°		°
−82·5	18	4·3	−80	1	4
−85·0	18	2·0	−85	1	1
−87·5	18	0·5	−87	1	1
90	17	0·6	90	1	0
+87·5	19	1·9	+87	1	2
+85·0	19	3·9	+85	1	3
+82·5	17	6·1	+83	1	3
			+80	1	5

The point of least rotation would seem at either place to be from 1° to 3° on the — side of 90°, or to indicate that the true plane passes through the part of the blue sky under examination,—the observer's eye,—and, for the third point, a spot a little *above* the sun; an indication of the neutral points of ARAGO, BABINET, and BREWSTER.

CHAPTER V.

METEOROLOGICAL OBSERVATIONS.

Appended to the Meteorological Observations and their reductions in vols. 2, 3, 4 and 5, there are such full accounts of the instruments, observers, and methods of reduction, that nothing remains to be done here but to collect the results for the three stations; the first of which, for the sea-level, is the Titania yacht, in Santa Cruz roads; the second, at 8903 feet of elevation, is Guajara; and the third, at 10,702 feet of elevation, is Alta Vista.

(1.) *Hourly Variations.*

From the means of three days of hourly observations in the 'Titania,' two days at Guajara, and two at Alta Vista, the following Table has been prepared, showing the corrections to reduce the barometer, thermometer, and depression of the dew-point, observed at any one hour, to the mean for the whole twenty-four hours.

By reason of the very short period that these observations extend over, the results are rough, with those accidental variations which the employment of a greater number of days would have tended to clear away, and which might have been somewhat smoothed down, quite legitimately, in making out a general table; but I thought it better, on the whole, to give the actual numbers resulting from the arithmetical operations, as being more adapted to serve all the purposes suggested for the Expedition.

The readings of the barometer, it may be here remarked once for all, have in every case been reduced to 32°, and to the Greenwich standard; and the depressions of dew-point and elasticities of vapour have been calculated by Dr. APJOHN'S formula for observations of wet- and dry-bulb thermometers, whose index errors have been carefully applied in every case.

Table I.

Hour.	Sea-level.			Guajara.			Alta Vista.		
	Barometer.	Dry-bulb thermometer.	Depression of dew-point.	Barometer.	Dry-bulb thermometer.	Depression of dew-point.	Barometer.	Dry-bulb thermometer.	Depression of dew-point.
h	inch.	°	°	inch.	°	°	inch.	°	°
6 A.M.	−·006	+2·1	+1·4	−·007	+3·7	−1·4	+·030	+4·0	+1·0
7 A.M.	−·011	+1·1	+1·1	−·008	+2·4	+0·6	+·004	+1·0	+0·9
8 A.M.	−·012	−0·2	−0·3	−·020	−0·4	−3·0	−·014	−2·4	−2·6
9 A.M.	−·026	−0·7	+0·1	−·036	−2·6	−3·4	−·019	−4·1	−0·9
10 A.M.	−·029	−0·6	+0·6	−·042	−5·0	−8·4	−·030	−6·8	−4·2
11 A.M.	−·024	−1·2	+0·2	−·040	−7·2	−9·9	−·026	−7·2	−4·2
0 P.M.	−·008	−2·3	−1·1	−·036	−7·5	−5·6	−·019	−7·0	−4·4
1 P.M.	·000	−2·7	−1·6	−·027	−8·2	−7·6	−·016	−7·5	−9·2
2 P.M.	+·008	−3·3	−3·5	−·024	−8·8	−5·9	−·006	−8·4	−10·2
3 P.M.	+·015	−3·3	−3·5	−·012	−8·0	−7·2	+·008	−7·3	−9·2
4 P.M.	+·030	−2·7	−4·0	−·006	−6·9	−3·9	+·013	−5·1	−6·5
5 P.M.	+·021	−2·3	−2·9	+·002	−4·0	−3·2	+·017	−0·6	−3·7
6 P.M.	+·013	−1·9	−2·2	+·002	−1·2	0·0	+·010	+1·8	−2·0
7 P.M.	+·001	−0·4	−1·0	−·003	+0·7	+2·4	+·005	+2·7	+0·4
8 P.M.	−·011	+0·7	+1·0	−·010	+1·0	−0·6	·000	+3·0	+2·2
9 P.M.	+·021	+0·7	+1·0	−·014	+3·4	+1·6	−·012	+3·8	+4·8
10 P.M.	−·029	+1·2	+1·8	−·008	+3·8	+3·2	−·016	+3·8	+5·7
11 P.M.	−·019	+1·4	+0·9	−·004	+5·2	+5·4	−·014	+3·8	+7·6
0 A.M.	−·004	+1·5	+1·2	+·012	+5·2	+4·5	−·013	+4·3	+5·8
1 A.M.	+·010	+2·0	+1·7	+·027	+5·7	+6·5	−·004	+4·9	+8·7
2 A.M.	+·019	+2·3	+2·3	+·039	+6·1	+7·9	+·013	+4·4	+7·4
3 A.M.	+·025	+2·4	+2·7	+·055	+7·1	+9·1	+·024	+5·4	+7·4
4 A.M.	+·025	+2·8	+2·6	+·057	+7·5	+9·1	+·030	+6·2	+3·6
5 A.M.	+·029	+3·1	+2·3	+·058	+7·7	+9·8	+·042	+6·1	+3·0

Table II.

Comparison of Hourly Variations at the three Stations.

	Sea-level.		Guajara.		Alta Vista.	
	Time.	Deviation from mean of twenty-four hours.	Time.	Deviation from mean of twenty-four hours.	Time.	Deviation from mean of twenty-four hours.
		in.		in.		in.
Barometer pressure, maximum A.M.	10 A.M.	·029	10 0 A.M.	·042	10 A.M.	·030
Barometer pressure, minimum P.M.	4 P.M.	·030	5 30 P.M.	·002	5 P.M.	·017
Barometer pressure, maximum P.M.	10 P.M.	·029	9 0 P.M.	·014	10 P.M.	·016
Barometer pressure, minimum A.M.	5 A.M.	·029	5 0 A.M.	·058	5 A.M.	·042
Daily range	.....	·059	.....	·100	.....	·072
		°		°		°
Temperature, maximum	2 P.M.	3·3	2 0 P.M.	8·8	2 P.M.	8·4
Temperature, minimum	5 A.M.	3·1	5 0 A.M.	7·7	4 A.M.	6·2
Daily range	.....	6·4	.....	16·5	.....	14·6
		°		°		°
Depression of dew-point, maximum	4 P.M.	4·0	11 0 A.M.	9·9	2 P.M.	10·2
Depression of dew-point, minimum	3 A.M.	2·7	5 0 A.M.	9·8	1 A.M.	8·7
Daily range	.....	6·7	.....	19·7	.....	18·9

The chief purpose of the above Tables is to serve in the reduction of isolated observations to the daily mean: we may however at once draw some interesting conclusions with reference to low and high stations. Thus at the level of the sea there are two regular and equal tides in the barometer, but on the mountain there is a tendency to lose the afternoon minimum and evening maximum, and to show in the twenty-four hours only one unequally-sided wave, having its minimum at 5 A.M., and its maximum at 10 A.M.

On the mountain the daily range of the barometer is rather larger than at the sea-level; and, as with the wave feature already adverted to, is greater at 8903 feet, than at 10,702 feet. Similarly, with the daily range of the temperature and the dew-point, they are nearly three times greater on the mountain than below, but are rather greater always at Guajara than at Alta Vista.

In the epochs and characteristics of the *elevated* barometric maxima and minima, there will be immediately perceived a resemblance to the effects of applying the usual correction for "elasticity of vapour," to deduce the pressure of dry atmosphere at a lower station*; and on introducing the same correction (viz. the elasticity of vapour due to the temperature of the dew-point), the above quantities become, for the

	inch.	inch.	inch.	inch.
Sea-level . .	+·008	−·004	+·008	−·013
Guajara . .	+·060	−·009	+·023	−·072
Alta Vista . .	+·012	+·004	+·004	−·021

Further illustrations of the effects of height in the hourly variations are given in Plate XXXVI., where the hourly readings of the instruments on a corresponding day above and below are graphically represented.

(2.) *Daily Means.*

Towards procuring the daily means of barometer, thermometer, and dew-point, there were never less than four observations each day on board the yacht, and seldom less than three on the mountain; these being corrected by the foregoing Tables of hourly variations, and meaned, are exhibited in the following Tables, and part of them in Plate XXXVII.

* See Mr. J. Johnson's "Oxford Observations" for 1856.

Table I.

Daily Means of Observations of Meteorological Journal at Sea-Level.

Date.	Barometer, corrected daily mean.	Dry-bulb, corrected daily mean.	Depression of dew-point, corrected daily mean.	Temperature of sea-water.	Date.	Barometer, corrected daily mean.	Dry-bulb, corrected daily mean.	Depression of dew-point, corrected daily mean.	Temperature of sea-water.
	inches.	°	°	°		inches.	°	°	°
1856, July 13.	30·046	73·3	12·0	69·9	1856, Aug. 19.	30·011	75·0	10·3	
14.	29·986	74·6	13·2	69·8	20.	30·058	73·2	10·4	72·5
15.	30·051	75·5	17·4	70·1	21.	30·109	73·6	9·4	72·8
16.	30·106	73·4	14·8	70·3	22.	30·125	73·4	10·8	
17.	30·069	71·0	15·1	69·9	23.	30·038	72·6	12·8	
18.	30·038	72·4	13·7	69·8	24.	30·008	72·8	13·4	
19.	30·045	73·5	7·6	70·7	25.	30·015	74·3	10·8	73·0
20.	30·035	74·1	7·2	71·8	26.	29·985	75·2	15·9	
21.	30·003	72·6	7·0	70·9	27.	29·925	77·8	19·6	
22.	30·001	72·0	10·0	71·8	28.	29·965	76·1	12·0	
23.	30·055	72·1	13·2	70·5	29.	30·019	73·6	6·0	74·0
24.	30·117	72·0	12·3	71·0	30.	30·015	75·2	6·5	75·0
25.	30·153	71·7	12·0	70·8	31.	29·993	74·1	7·0	74·8
26.	30·133	72·5	13·4	71·0	Sept. 1.	29·921	74·0	9·4	
27.	30·046	74·5	16·5	71·5	2.	30·035	74·8	10·8	
28.	29·963	75·4	16·4	72·5	3.	30·080	73·6	8·8	73·8
29.	29·951	72·9	8·2	72·0	4.	30·093	74·3	12·4	73·5
30.	30·006	73·0	8·0	70·5	5.	30·090	74·0	13·0	73·8
31.	30·044	73·1	8·6	72·0	6.	30·123	74·8	11·4	
Aug. 1.	30·031	71·3	7·1	71·8	7.	30·201	73·7	8·8	
2.	30·003	72·0	8·1	72·0	8.	30·145	73·1	12·1	74·0
3.	30·035	72·6	13·6	72·0	9.	30·081	73·1	12·5	
4.	30·106	74·2	12·2		10.	30·105	73·3	10·6	
5.	30·125	72·8	11·4		11.	30·057	74·4	13·3	
6.	30·145	73·2	13·5	71·8	12.	29·991	73·6	10·1	
7.	30·141	72·7	11·1		13.	30·008	73·6	8·6	75·0
8.	30·080	72·6	13·4		14.	30·083	73·4	9·6	
9.	30·040	72·5	13·7		15.	30·119	78·4	12·5	
10.	30·044	72·2	11·4	72·0	16.	30·138	78·8	17·3	74·2
11.	30·041	75·5	12·8	72·2	17.	30·034	78·3	17·0	
12.	30·019	74·6	12·2		18.	30·024	77·2	13·1	
13.	30·029	73·3	10·6		19.	30·109	75·6	7·3	
14.	30·021	74·8	12·0		20.	30·110	77·0	12·4	75·0
15.	30·001	74·5	7·6		21.	30·076	74·8	9·2	
16.	30·017	74·1	9·6		22.	30·115	73·7	9·0	
17.	30·020	74·8	15·2		23.	30·163	74·7	12·7	74·6
18.	30·024	73·9	9·8						

Table II.

Daily Means of Observations of Mountain Meteorological Journal at Guajara Station.

Date.	Barometer, corrected daily mean.	Dry-bulb, corrected daily mean.	Depression of dew-point, corrected daily mean.	Date	Barometer, corrected daily mean.	Dry-bulb, corrected daily mean.	Depression of dew-point, corrected daily mean.
1856.	in.	°	°	1856.	in.	°	°
July 16.	21·930	61·8	31·2	Aug. 2.	21·919	58·2	28·7
17.	21·780	60·0	51·2	3.	21·865	55·9	29·8
18.	21·880			4.	21·884	55·5	16·3
19.	21·970	65·1	22·1	5.	21·914	56·8	32·1
20.	22·000	64·6	29·9	6.	21·979	56·4	25·6
21.	21·996	62·7	33·6	7.	21·972	58·4	31·3
22.	21·881	60·4	32·8	8.	21·921	59·3	47·4
23.	21·837	56·7	36·9	9.	21·867	57·1	44·4
24.	21·888	59·6	36·3	10.	21·898	57·0	44·4
25.	21·921	59·5	38·3	11.	21·928	59·9	40·4
26.	21·950	62·7	46·3	12.	21·956	65·0	30·1
27.	21·922	64·8	39·0	13.	21·984	63·7	29·3
28.	21·883	65·2	41·4	14.	22·011	62·3	25·0
29.	21·919	65·1	47·1	15.	22·004	60·2	29·2
30.	22·005	65·1	44·0	16.	21·993	62·4	31·5
Aug. 1.	21·959	58·9	34·3	17.	21·937	63·5	41·7

Table III.

Daily Means of Observations of Mountain Meteorological Journal at Alta Vista.

Date.	Barometer, corrected daily mean.	Dry-bulb, corrected daily mean.	Depression of dew-point, corrected daily mean.	Date.	Barometer, corrected daily mean.	Dry-bulb, corrected daily mean.	Depression of dew-point, corrected daily mean.
1856.	in.	°	°	1856.	in.	°	°
Aug. 21.	20·589	54·7	26·8	Sept. 8.	20·576	48·6	13·0
22.	20·613	56·7	22·1	9.	20·558	50·8	38·2
23.	20·564	58·5	30·9	10.	20·568		
24.	20·522	55·8	22·8	11.	20·493	48·1	34·2
Sept. 1.	20·372	44·8	35·3	12.	20·374	43·5	40·1
2.	20·452	45·3	26·1	13.	20·385	44·4	36·2
3.	20·468	46·1	24·5	14.	20·467	40·9	21·4
4.	20·485	49·7	29·2	15.	20·572	38·8	0·0
5.	20·508	51·8	27·4	16.	20·599	41·9	2·9
6.	20·553	50·9	16·9	17.	20·583	44·2	10·4

Variation of Daily Means.

Comparing all these determinations together for results, and beginning with the barometer, we find the variations at the sea-level to be somewhat greater than those on the mountain, and singularly inconsistent with them, except on one or two occasions, as the September storm at Alta Vista.

On the other hand, the variations of the thermometer are much greater on the mountain than at the sea-level, having amounted on Guajara to 9°·7 against 4°·5 at the sea-level, and on Alta Vista to 19°·7 against 6°·2 at the lower level for the same period.

The dew-point exhibits greater variations still, amounting on Guajara to 34°·9 against 9°·4 at the sea-level, and on Alta Vista to 40°·1 against 13°·6 at the lower level for the same period.

These variations of daily means exhibit inexplicable discordances, in no small measure on account of so small a portion of their cycle, viz. the year, being included in the observations; and before coming to the consideration of the absolute quantities for each day, it may be well to consider the monthly variations.

(3.) *Monthly Means.*

On taking the arithmetical means, the results indicated by the curves were powerfully confirmed, viz. that on the mountain, the maxima of temperature and dryness are earlier than below; summer, in fact, at a great height, is there nearly coincident with the solstice. Thus while at the sea-level the temperature went on increasing throughout July, August, and September, it was sensibly decreasing at Guajara in July and August; and at Alta Vista, in August and September, it was very rapidly falling. On going below the sea-level, or to the sea-water itself, the law was carried on further still, the numbers being as follows:—

Date.	Sea-level.			Sea-water, temperature of.	Guajara.			Alta Vista.		
	Barometer.	Temperature.	Depression of dew-point.		Barometer.	Temperature.	Depression of dew-point.	Barometer.	Temperature.	Depression of dew-point.
	inches.	°	°	°	inches.	°	°	inches.	°	°
1856, July	30·045	73·1	11·4	70·9	21·918	62·4	37·9			
August ...	30·036	73·8	11·3	72·8	21·941	59·6	33·0	20·572	56·4	25·6
September	30·083	74·9	11·4	74·2				20·500	46·0	23·7

These means represent the whole of the observations made in each month at the several stations; at the sea-level they include nearly the whole of each month, but on the mountain only about half a month each; this circumstance, however, will not touch the great fact now brought to light, of the mean temperature arriving at its maximum earlier at 10,702 feet than at 8903, and at 8903 earlier than below it.

Over and above this effect, the temperature appears to follow the law of decrease with altitude, but in an accelerating ratio so far as these *three* stations would indicate, which will be considered in the department of the "*peripatetic*" observations; and I would now rather advert to the most remarkable feature of all in the mountain climate, viz. the excessive dryness, amounting at Guajara, in the contrary terms of humidity (saturation=100), to 26, and at Alta Vista to 38, as the mean for two months, against 66 at the sea-level; or, in terms of grains of moisture in a cubic foot of air equally compressed in each case, to 1·5, 1·6, and 6·2.

Extreme Readings.

At the sea-level the highest maximum temperature daily mean was 78°·8 on Sep-

tember 16, and the lowest 71°·0 on July 17. At Guajara 65°·2 on July 28, and 55°·5 on August 4. At Alta Vista 58°·5 on August 23, and 38°·8 on September 15. Again, the greatest maximum mean daily depression of the dew-point at the sea-level was 19°·6 on August 27, and the minimum 6°·0 on August 29. At Guajara 51°·2 on July 17, and 16°·3 on August 4. At Alta Vista 40°·1 on September 12, and 0°·0 on September 15. To this we may add as examples of atmospheric dryness, that among the isolated observations on Guajara, the amount of depression of the dew-point was 58°·5 on July 17, the temperature being 51°·5; which gives only 0·4 grain of water in a cubic foot of air, and a humidity of no more than 10, while at the sea-level for the same instant it was 62.

(4.) *Winds.*

In the journals, at the sea-level and on the mountain, the velocity of the wind was entered in miles per hour by estimation. Guajara station, being quite on the top of the mountain there, and undominated by any neighbouring points, was favourable for getting the true direction of the wind. Alta Vista, on the contrary, being on the eastern slope of the Peak, was faulty as a site; and generally, by day, in normal weather, there was an east wind blowing up from the plain, and by night a west wind blowing down from the Peak.

Taking means rudely of the directions and strength of the wind as observed at each place, an approximate mean velocity and direction of the wind on each day has been obtained, and has been entered in Plate XXXVII. for the period to which it refers.

From these quantities, taking the mean of all the days of corresponding observations, we find that during thirty-four days at the sea-level, the mean velocity of the wind was 4·5 miles per hour, while on Guajara it was only 2·3 milès for the same time. On Alta Vista, again, the mean velocity during twenty-three days was 3·3 miles per hour, while it was 5·8 miles at the sea-level for the same period.

Between Guajara and the sea there is little change in the general direction of the wind, northerly being in both places to southerly as 2 to 1. On the Alta Vista, on the other hand, northerly directions were to southerly only as 1 to 10, the old proportion at the sea-level still remaining. Moreover, while at the sea-level about one-twentieth part of the whole wind was from the east, and none from the west, there was, with the same amount of east wind at Alta Vista, one-eighth of the whole from the west.

(5.) *Height of Stations.*

The great length of time during which simultaneous meteorological observations were kept up at either mountain station and on board the yacht, have afforded a good insight into the uncertainties still existing in the best barometrical formulæ for the determination of heights. The varying results from the means of successive days were very difficult to interpret; but when the hourly variations were tried, and found to exhibit a fluctuation through upwards of 170 feet at Guajara, and 280 feet at Alta Vista, the temperature of the upper station was clearly shown to be the agent at fault; and this

conclusion we have since ascertained to be remarkably borne out by the "peripatetic" observations on September the 8th. For, ascending the Peak on that day, and passing through a locality where there was a visible escape of volcanic steam, and a sensible increase of the temperature of the air, our observations show that a barometrical hump was thereby produced on the side of the mountain to the extent of 368 feet.

The formula employed was that of La Place, as adapted to practice by Francis Baily in his Astronomical Tables.

Hourly Variation of Heights.

The following two Tables will show the manner of variation of the computed heights with change of the several meteorological conditions, one of the tables being also exhibited graphically in Plate XXXVI.

Guajara Station.

Date.	Hour.	Corrected barometer, at sea-level.	Thermometer.	Depression of dew-point.	Barometer, corrected on mountain.	Thermometer.	Depression of dew-point.	Altitude above sea-level.	Radiation at Guajara.
1856.		in.	°	°	in.	°	°	feet.	°
Aug 1.	4 A.M.	30·031	67·8						
	6 A.M.	30·052	69·7	6·3	21·955	57·5	37·3	8814·6	
	7 A.M.	30·046	70·0	5·6	21·952	58·6	36·8	8830·0	+ 52·4
	8 A.M.	30·043	71·8	7·8	21·975	60·0	39·2	8826·2	+ 66·7
	9 A.M.	30·055	72·6	8·7	21·992	61·9	39·9	8840·8	+ 77·4
	10 A.M.	30·061	71·5	7·3	22·000	64·0	38·6	8844·5	+ 82·8
	11 A.M.	30·053	71·7	7·9	21·998	66·3	41·5	8863·0	+ 82·7
	0 P.M.	30·044	74·0	10·2	21·995	66·7	40·4	8883·0	+101·6
	1 P.M.	30·032	75·8	12·0	21·975	66·4	42·2	8910·7	+ 85·8
	2 P.M.	30·023	75·1	10·4	21·978	66·5	41·5	8892·7	+ 82·3
	3 P.M.	30·019	73·8	9·2	21·966	66·7	41·3	8894·9	+ 74·9
	4 P.M.	29·995	73·8	9·2	21·960	65·5	40·5	8869·0	+ 73·0
	5 P.M.	29·991	74·3	10·0	21·946	62·4	38·8	8860·8	+ 62·4
	6 P.M.	29·996	74·8	10·0	21·958	60·5	35·7	8835·9	+ 62·0
	7 P.M.	30·003	72·6	8·2	21·961	58·4	35·4	8799·4	+ 2·5
	8 P.M.	30·015	71·0	5·7	21·968	57·3	36·9	8777·5	− 4·5
	9 P.M.	30·024	70·8	5·4	21·972	55·5	35·4	8762·6	− 4·2
	10 P.M.	30·031	70·3	4·6	21·966	55·9	32·1	8775·7	− 4·1
	11 P.M.	30·027	70·0	4·9	21·968	55·3	27·4	8761·0	− 4·3
	0 A.M.	30·018	69·8	4·6	21·956	54·3	27·9	8757·5	− 4·1
	1 A.M.	29·999	69·0	5·0	21·935	53·8	26·6	8753·1	− 3·8
	2 A.M.	29·994	68·3	4·0	21·931	53·9	26·1	8748·9	− 4·4
	3 A.M.	29·983	68·3	4·0	21·923	53·3	24·8	8744·2	− 3·9
	4 A.M.	29·986	67·8	3·9	21·919	52·6	23·0	8741·0	− 3·0
	5 A.M.	29·985	67·8	4·9	21·918	52·7	22·3	8742·0	− 2·4
	6 A.M.	30·008	68·3	4·9	21·918	53·5	23·6	8757·3	+ 26·8
							Mean.....	8843·45	

Alta Vista.

Date.	Hour.	At sea-level.			On mountain.			Altitude above sea-level.
		Barometer, corrected.	Thermometer.	Depression of dew-point.	Barometer, corrected.	Thermometer.	Depression of dew-point.	
1856.		in.	°	°	in.	°	°	feet.
Aug. 21.	4 A.M.	30·054	71·8					
	6 A.M.	30·095	71·8	7·8	20·541	48·7	18·5	10653·9
	7 A.M.	30·103	73·3	9·3	.....	.....	21·0	
	8 A.M.	30·108	73·8	10·0	20·577	54·4	24·2	10702·7
	9 A.M.	30·132	74·4	9·8	20·594	58·9	31·4	10758·5
	10 A.M.	30·134	75·6	10·4	20·590	62·6	36·8	10820·4
	11 A.M.	30·132	77·1	11·1	20·592	66·0	37·2	10869·1
	0 P.M.	30·109	77·1	11·1	20·589	65·2	41·0	10843·6
	1 P.M.	30·099	76·3	10·1	20·587	65·5	39·1	10831·6
	2 P.M.	30·101	76·0	11·3	20·588	63·4	36·4	10805·2
	3 P.M.	30·092	74·8	10·0	20·591	61·4	34·6	10757·0
	4 P.M.	30·089	75·8	13·2	20·602	58·4	29·6	10717·2
	5 P.M.	30·114	74·6	10·8	20·607	56·3	26·5	10697·5
	6 P.M.	30·125	74·3	10·3	20·610	54·7	23·1	10682·5
	7 P.M.	30·139	73·8	11·0	20·613	53·3	21·7	10670·7
	8 P.M.	30·155	73·6	9·8	20·621	52·3	22·4	10661·4
	9 P.M.	30·167	73·8	9·9	20·619	51·2	19·8	10665·0
	10 P.M.	30·173	73·8	9·6	20·618	51·8	18·8	10678·8
	11 P.M.	30·158	73·6	10·6	20·614	48·8	19·1	10634·6
	0 A.M.	.....	.....	9·9				
	1 A.M.	30·130	73·0	8·8	20·595	48·4	19·2	10623·6
	2 A.M.							
	3 A.M.							
	4 A.M.	30·104	72·1	8·2	20·591	49·1	21·1	10602·1
	5 A.M.	30·105	71·6	8·5	20·595	48·6	19·2	10587·2
	6 A.M.	30·125	71·8	8·8	20·598	49·3	19·1	10586·0
							Mean.....	10707·08

Daily Variations of Heights.

From the daily means already given for each of the three stations, the computed height of Guajara varies thus:—

Date.	Feet.	Date.	Feet.	Date.	Feet.	Date.	Feet.
July 21.	8793·3	July 28.	8950·4	Aug. 5.	8961·7	Aug. 12.	8899·8
22.	8913·6	29.	8868·3	6.	8897·0	13.	8848·8
23.	8988·0	30.	8810·3	7.	8916·0	14.	8807·9
24.	9005·6	Aug. 1.	8821·3	8.	8931·8	15.	8776·3
25.	8993·6	2.	8845·9	9.	8942·4	16.	8822·1
26.	8974·5	3.	8930·0	10.	8902·9	17.	8913·0
27.	8966·5	4.	8982·6	11.	8917·7		

and that of Alta Vista as follows:—

Date.	Feet.	Date.	Feet.	Date.	Feet.	Date.	Feet.
Aug. 21.	10,688	Sept. 2.	10,715	Sept. 8.	10,666	Sept. 14.	10,674
22.	10,691	3.	10,731	9.	10,656	15.	10,597
23.	10,687	4.	10,768	11.	10,708	16.	10,617
24.	10,689	5.	10,754	12.	10,747	17.	10,562
Sept. 1.	10,704	6.	10,720	13.	10,758		

For the height of Guajara, the mean of its series, or 8903 feet, may be adopted.

For the height of Alta Vista, the mean of the whole series is 10,691 feet; but seeing that decidedly exceptional weather began on September 14, and that the mean of the days from August 21 to September 13 is 10712, the mean of the two determinations may probably be the closest approximation to the real height, which therefore comes out 10,702 feet.

(5*.) *Difference of Meteorological Elements between the Yacht in Santa Cruz Roads and the Town of Orotava.*

The mountain observations having been necessarily compared with the series of Captain CORKE on board the 'Titania,' and that vessel lying all the time in Santa Cruz Roads, at the eastern end of Teneriffe and on the southern coast, while the Peak is rather towards the western end and on the northern coast;—it became desirable to ascertain whether any, and what constant differences might occur between that station of the yacht, 30 miles N. 60° E. of the Peak, and the town of Orotava, which lies only at a distance of 12 miles and in the direction N. 30° E.

Facilities for this purpose were afforded by Mr. FRANZ KREITZ, a skilful German watch-maker, formerly of Hamburg, who zealously undertook to observe some of the instruments kindly lent by Admiral FITZROY on the part of the Board of Trade.

Having established these instruments under good circumstances of exposure at M. KREITZ's, on August 29, I left him with instructions for observing them simultaneously to the ordinary Yacht times of observation; and on September 24 he furnished me with a series of readings of the barometer and dry- and wet-bulb thermometers, taken three times a day, or oftener, for the whole of the intervening period. These observations having been duly corrected for index errors, and reduced in a manner similar to the Yacht observations, are found, on the mean of each day, to give the following series of corrections to reduce the Orotava series to the Santa Cruz:—

Date.	Barometer.	Temperature.	Depression of dew-point.	Date.	Barometer.	Temperature.	Depression of dew-point.
1856.	inches.	°	°	1856.	inches.	°	°
August 30.	+·055	−0·1	−0·7	September 11.	+·063	+0·1	+2·9
31.	·134	+0·6	−0·2	12.	·082	−0·8	−0·8
September 1.	·064	−2·4	−0·4	13.	·107	−3·0	−3·8
2.	·058	−1·7	+1·7	15.	·043	+2·1	+5·0
3.	·061	−1·9	+0·4	16.	·015	+4·0	+9·2
4.	·067	−0·9	+3·8	17.	·036	+4·3	+11·8
5.	·063	−0·4	+3·3	18.	·062	+2·0	+7·3
6.	·047	−1·6	+1·2	19.	·074	+1·2	+2·9
7.	·078	−1·7	−0·4	20.	·090	+2·4	+7·8
8.	·076	−2·0	+0·4	21.	·063	−0·9	+1·6
9.	·051	−1·6	+1·9	22.	·083	−1·0	+1·2
10.	+·053	−0·8	−0·1	23.	+·099	+1·0	+1·8

The mean barometrical difference appears to answer very closely to the elevation of M. KREITZ's house above the level of the sea, or about 80 feet, the temperature of which

appears in average weather to have been 1°·1 greater, and the depression of the dew-point 1° less than on board the yacht. Exceptional weather occurred from September 13 to September 20, and appears to have been in connexion with the Alta Vista storm of the 14th, though not in exact coincidence. As this was a period during which the computed barometric altitudes of the mountain station gave very wild results compared with the yacht, we have computed the upper observations again as compared with Orotava; but the discordances are even greater, as the enclosed numbers will show, and they are evidently in connexion with the same general disturbances of the atmosphere, thereby reflecting credit on both the lower observers.

Date.	Height of Alta Vista above Orotava.	Correction to mean.	Height of Alta Vista above yacht.	Correction to mean.
	feet.	feet.	feet.	feet.
1856, Sept. 1.	10,672	− 30	10,704	− 10
2.	10,680	− 38	10,715	− 21
3.	10,695	− 53	10,731	− 37
4.	10,715	− 73	10,768	− 74
5.	10,699	− 57	10,754	− 60
6.	10,695	− 53	10,726	− 32
8.	10,618	+ 24	10,666	+ 28
9.	10,627	+ 15	10,656	+ 38
11.	10,646	− 4	10,708	− 14
12.	10,650	− 38	10,747	− 53
13.	10,692	− 50	10,758	− 64
15.	10,534	+108	10,597	+ 97
16.	10,559	+ 83	10,617	+ 77
17.	10,482	+160	10,562	+132

Boiling-point Thermometer.

A boiling-point thermometer, made by Mr. ADIE of Edinburgh, graduated to tenths, and reading to hundredths of a degree, and since admirably tested by my friend Mr. WELSH of the Kew Observatory, was observed with at Guajara, Alta Vista and the Peak, but not so often as I see would have been desirable; so that I can only now state that for approximative purposes Captain BOILEAU's Tables are most satisfactory, giving by two observations the height of Guajara subject to a correction of +40 feet, Alta Vista +70, and the Peak −26; the corrections of simultaneous barometrical altitudes being +122, +98, and −2 feet.

(6.) *Peripatetic Observations.*

In all the journeyings up and down the mountain, the altitudes were measured by myself with a sympiesometer, especially made for the occasion by Mr. JOHN ADIE. From the simultaneous readings of this instrument with the barometer at Orotava, Guajara, and Alta Vista, a temperature and an altitude correction have been made out, and have been applied in every case to reduce the sympiesometer reading to what our barometer, corrected, would have shown at the same place and time. The calculation of the height was then performed as with a barometer reading. The height so found

was corrected further for the variation of barometric height with the hour of the day, as indicated by the observations already given, and arranged in the following approximate Table, where the sign shows the manner in which the tabular feet are to be applied as *corrections* to the barometrical, to give the true altitude; the arguments along the top of the Table being the approximate height of the station, and on the side, the hour of the day, apparent solar time.

Correction for Barometrical Altitudes for hour of day, and approximate height.					
	Approximate altitude of station in feet.				
Approximate solar time of observation.	10,000.	8000.	6000.	4000.	2000.
h					
6 A.M.	+ 15	+12	+ 8	+ 5	+ 2
7 A.M.	+ 5	+ 4	+ 2	+ 2	+ 1
8 A.M.	0	0	0	0	0
9 A.M.	− 20	−15	−10	− 6	− 3
10 A.M.	− 70	−52	−35	−23	−12
11 A.M.	−100	−75	−50	−33	−17
0 P.M.	−100	−75	−50	−33	−17
1 P.M.	−115	−80	−60	−40	−20
2 P.M.	− 95	−72	−50	−33	−17
3 P.M.	− 60	−45	−30	−20	−10
4 P.M.	− 30	−22	−15	−10	− 5
5 P.M.	− 10	− 8	− 5	− 4	− 2
6 P.M.	− 5	− 4	− 2	− 2	− 1

For the height of the Peak, measured during an ascent on September 8, and resting on five hourly observations from 11 A.M. to 4 P.M., a special method was employed. The barometer was simultaneously observed at Alta Vista, and gave the height of that station, for the interval, too high by 35 feet, this quantity being compounded of the daily and the hourly correction. Then increasing this quantity to 41 feet, for the proportion between the height of the Alta Vista and the sympiesometer station in a cleft on the western side of the crater at the summit of the Peak, and levelling thence to the culminating point of the whole, a part of the north-eastern wall of the crater, we have 12,198 for the height of the Peak of Teneriffe.

A series of heights of notable points will then run as follows:—

		Engl. feet.
	Culminating point of the Peak	12,198
Cone of eruption.	Base of small cone on the eastern side, or Rambleta	11,745
Cone of eruption.	Narix	11,600 (?)
Cone of eruption.	Ice cavern	11,044
Cone of eruption.	Alta Vista	10,702
Cone of eruption.	Estancia de los Ingleses	9,710
Cone of eruption.	Base of steepest portion of great cone of eruption, where it adjoins Montana Blanco	8,930

	Engl. feet.
Guajara, or culminating point of wall of great crater of elevation	8,903
Floor of crater of elevation, generally	7,200
Cañadas, or outer boundary of the floor	6,900

From this last level there is a nearly uniform descent on the Orotava side, at an angle of about 12 degrees to the sea beach.

The height of the Narix entered above, is derived from the sympiesometer observations made half an hour before reaching, and three-quarters of an hour after having passed it, on our slow ascent of the Peak on September 8. The instruments were observed also at the Narix, *i. e.* within about ten yards of the little vent-hole, out of which about as much steam was issuing as a 2-inch pipe might supply from a low-pressure boiler. As far as I knew at the time, the Narix observations were equal in value to any that were made that day, and were accordingly computed with the rest; they gave a height of 11,868 feet, or upwards of 100 feet higher than the next observation-point which we reached in our continual ascent of the regular slope of the mountain. A difference of 10 degrees in the temperature at the Narix and the other stations looked at first like an error of observation; but on referring to the original note-book, and finding that the increase was not an exact ten, and had been participated in by the thermometer of the sympiesometer, the dry-bulb and the wet-bulb, there could be no doubt of the observations being good, and fully trustworthy in as far as lay in them.

The instruments then may be considered to show that there is an escape of volcanic heat at this point; and seeing that the depression of the dew-point is somewhat increased also, we may look on the steam as a consequence rather than the cause of this local warmth. Reducing the temperature above and below the Narix to the mean for 24 hours, and taking the mean of them, 46°·7 is given as the true temperature of the level of that spot, the observed, after similar correction, being 57°·5. Similarly with the depression of the dew-point, 28°·7 ought to have been found, but the instrument showed 32°·2.

(7.) *Meteorological Descent and Ascent of the Mountain.*

In descending from Alta Vista to Orotava on August 25, and ascending again on August 30 with the large equatorial, I took the opportunity of making careful meteorological observations, placing the instruments we had used on the mountain in a sort of portable observatory, or tall box, fastened on a mule in such a position as to hang nearly vertical; and, while made with numerous openings above and below and on the sides, to admit of the circulation of air, it was covered outside with bright tinfoil, to guard against effects of solar radiation. The mule was stopped whenever observations were to be made, or the wet-bulb to be wetted; and the results are as worthy of confidence as those made at one of the stationary positions. They were, however, necessarily loaded with the hourly variations, and to eliminate these, tables of double entry have been constructed to reduce the thermometer and depression of dew-point, observed at any instant, to the

mean for 24 hours, at all levels from 0 to 11,000 feet; the materials for the construction of the Table being afforded by the results already given for Alta Vista, Guajara, and the yacht at Santa Cruz. These corrections having been applied, we have in the resulting quantities only the effect of height, wind, and such local circumstances as would affect also instantaneous ascents and descents of the mountain, were such possible.

The quantities are thus for August 25:—

Height in feet.	Temperature reduced to mean of twenty-four hours.	Dew-point depression reduced to mean of twenty-four hours.	Humidity, saturation = 100.	Wind.		Clouds.	
				Velocity.	Direction.	Upper.	Lower.
	°	°		miles per hour.			
10,710	64·5	29·1	37	1	S.E.	0	Dense.
9,769	63·6	31·4	34	2	W.	—	—
8,870	63·9	30·6	36	3	W.	—	—
8,375	65·8	36·6	29	6	W.	—	—
8,236	67·9	41·4	24	3	S.W.	—	0
7,436	70·6	35·5	32	1	S.W.	—	—
7,186	71·8	38·9	27	0	...	—	—
6,936	72·5	33·2	33	—	—	—	—
6,758	73·1	33·0	33	—	—	—	—
6,702	73·5	31·9	35	2	N.	—	—
6,069	75·0	29·4	38	2	N.	—	—
5,470	75·8	32·7	34	1	N.	0	Dense.
5,025	76·6	31·7	35	2	N.	—	—
5,448	81·4	20·1	52	...	...	—	—
3,379	85·3	18·6	55	0	...	—	0
2,460	81·3	17·7	57	2	N.	...	
1,948	75·8	12·9	66	3	N.	7 ⌒	
1,651	75·0	12·8	66	2	N.E.	8 ⌒	
1,000	73·6	9·9	72	0		8 ⌒	
803	74·0	10·7	70	0		8 ⌒	
548	74·1	11·4	69	2	N.E.	3 ⌒	
324	74·3	10·5	71	1	N.E.	2 ⌒	
5	74·7	10·6	71	0	...	3 ⌒	
24	75·7	11·0	70	0	—	0	0

And thus for August 30:—

Height in feet.	Temperature reduced to mean of twenty-four hours.	Dew-point depression reduced to mean of twenty-four hours.	Humidity, saturation = 100.	Wind.		Clouds.	
				Velocity.	Direction.	Upper.	Lower.
				miles per hour.			
13	76·8	6·8	80	0	...	10 ∩	
304	75·6	6·6	81	—	...	—	
839	74·1	6·6	81				
1,435	73·2	6·1	82				
1,837	72·7	5·8	83	—	...	—	
2,292	73·0	5·6	83	0	...	5 ∩	Near level of cloud, but it is dispersing.
3,460	74·1	6·9	80	0	...	2 ∩ ⊙ hot	Dense to seaward.
3,696	75·4	6·3	82	...	...	3 ∩	
4,157	76·7	14·4	62	0	...	5 ∩	Dense.
4,769	75·7	10·5	71	1	N.W.	7 ∩	—
5,160	73·9	20·5	51	1	N.W.	7 ∩	—
5,904	71·9	26·4	41	0	...	7 ∩	—
6,521	70·2	24·4	44	1	N.	7 ∩	—
6,875	69·0	25·3	43	1	N.	5 ∩	—
7,234	64·9	23·3	46	3	N.	5 ∩	—
7,792	67·9	25·3	43	3	S.W.	5 ∩	—
8,260	65·2	21·8	48	4	S.	5 ∩	—
8,976	60·5	19·7	51	3	S.W.	5 ∩	—
9,662	52·8	13·0	64	1	S.W.	3 ∩ _\	—
10,710	47·4	7·2	78	2	S.W.	3 \ and ∩ Cloud on Peak or close above station.	—

These quantities are likewise exhibited in the Plates XXXVIII. and XXXIX.

The first result deducible from the two preceding Tables, is the remarkable confirmation which they give, of Mr. WELSH's discovery in his balloon ascents, of a break in, or a very great anomalous deviation from, the law of decrease of heat with the elevation, at a height of a few thousand feet above the sea. The reason of this anomaly seems to be indicated at the same time; for it occurs not at any passage from one wind to another, not at any break in the slope of the mountain, but at the level of the cloud stratum. This is the only noteworthy circumstance that can be found accompanying the deviation from the law, and may arise partly from the reflexion of heat by the brilliant upper surface of the cloud, and partly, as suggested by Mr. WELSH, in connexion with the conversion of latent into sensible heat, dependent on the condensation of vapour into cloud. In either case, the practical result is the same; viz. that at any moderate height above the clouds, the temperature of the air is by no means so low as might have been computed from the usual hypsometric idea of gradation.

The second result is, further confirmation to GREEN's and SABINE's, of DANIELL's conclusion of dryness above the cloud stratum. From the sea-level to the clouds, 3000 feet high, the depression of the dew-point is small, but immediately after passing that height

the depression increases from 10° to 30°. On August 25, however, a rapid diminution is indicated at about 10,000 feet, and the concomitant circumstance is observed, that there is that day a cloud on the top of the Peak (12,000 feet high); and as in ascending we gradually came underneath the mist, we were evidently approximating to the conditions of our starting from the sea-level, with the 3000-foot stratum of cloud above us.

A third result we may draw is, that while the expected difference was found between the wind at the top and bottom of the mountain, viz. S.W. above and N.E. below, the stratum of cloud was not found in the space between the two, but in or below the middle of the N.E. current of air. This was certainly only the mountain cloud, which is limited in horizontal extent to a few miles; but even the sea- or the true N.E.-cloud, which was far more extensive,—stretching, in fact, as far as the eye could observe, when many thousand feet above it,—only reached to between 4000 and 5000 feet of elevation, while the N.E. wind extended in height from the very sea itself to about 9000 feet. This was the general state of things for over two months at Guajara, when the weather was settled in its N.E. trade; and it may be perhaps only when a storm comes to break up the adjustment, that a cloud finds itself occasionally, as may be seen about Table Mountain in South Africa, between two opposite currents of air, and made to spin round and round by their opposing action.

(8.) *Electricity.*

For upwards of a month, an electrometer (lent by Mr. AIRY) was observed daily on Guajara. The instrument had travelled so safely, that the two strips of gold-leaf that had been attached in England, were found in good working order in Teneriffe. The glass bell, however, having unfortunately been fixed by the maker in a wooden base, the contraction of this from excessive drought at last broke the bell. During the whole period of observation by day and by night, the electricity was moderate in quantity, and always resinous; this was during the season of the N.E. trade-wind, and within its influence, though above its clouds. Had the instrument lasted longer, something more varied, if not more interesting, would have been found; for our subsequent experiences at Alta Vista introduced us to a different current of the atmosphere, and at last to a complete change of weather; and on the very day that we left, September 19, a heavy shower of rain fell, accompanied with a cloud on the Peak, two or three flashes of lightning, and somewhat loud thunder. This was the first electric display we had seen since entering the region of the trade-winds on July 5, in lat. 37°, and it certainly came from the S.W. Occasionally I had thought at Guajara that there were indications of electricity in the forms of the clouds floating at a great height over the station from the S.W.; and on the night of August 1st and the morning of August 2nd (see Meteorological Journal), I watched with intense interest a large cloud that remained stationary over the mountain for seven hours, and was every moment altering its form, fitfully and instantaneously, more like an aurora than a cloud. On no occasion, however, was the electrometer affected; and on no occasion, indeed, did we cease to be under the domina-

tion of the lower polar current. At the sea-level there was a similar absence of electricity during the summer; but I have since been informed by a letter from my friend Mr. HAMILTON of Santa Cruz, that when the autumn set in there below in November, as it had done above in September, it brought S.W. wind, rain, and snow with it, and so much electricity, that a house in Orotava was destroyed by lightning.

(9.) *Alta Vista Storm of September 14th.*

From August 30th a decided change from the long-continued routine of the summer weather took place; a cirrous cloud formed on the Peak that day, immediately above our heads at Alta Vista; and the appearance of the fibres of misty cirri dissolving, reforming, and driving over the mountain top, was dazzlingly beautiful. I have had abundant experience of ordinary clouds on mountain tops, under 6000 feet in height; but they were always dull foggy mist, in fact NEWTON'S "grosser clouds;" and I can therefore speak positively to this "cirrous" cloud on the Peak being something unusual in its nature and mode of composition. A strong S.W. wind blew subsequently for three days; and though the weather settled again, we could not but be struck with the change that had occurred in the N.E. cloud. Still it formed its usual stratum at about 4000 to 5000 feet high, but its long rolls of cumuloni were broken up into separate and distinct cumuli; and on the south side of both Teneriffe and Grand Canary we could see similar bodies of clouds advancing from the S.W., climbing the steep sides of the island, and contesting the possession of the ridges day after day with the N.E. clouds. This remarkable aërial combat was carried on under our eyes with various success until September 11th, when the S.W. cloud obtained a preponderance, with a sinking barometer. The next day the S.W. cloud was decidedly the victor, while the N.E. cloud, simply to describe the actual facts, was retiring before it in broken and disorganized masses. The following day the barometer rose from 20·363 to 20·410, and the succeeding morning, the 14th, to 20·473; at this time, however, were perceived on the sea, between Teneriffe and Grand Canary, extraordinary appearances of some unusual and grand current from the S.W., for there were long curved lines traceable for fifty or more miles in their length, indicating a stream setting in between Teneriffe and Canary. The sky soon after became cloudy above our heads; at 1 P.M. a sudden and heavy shower of rain and hail came down; at 5 P.M. the cloud descended upon Alta Vista; and at 7 P.M. heavy rain began with a violent wind from the S., producing more than 2 inches of rain in a gauge before the next morning.

During this period the barometer remained almost stationary, the temperature was lowered five or six degrees; but the remarkable change was in the dew-point. At 9 A.M., on the 14th, the amount of depression was 46°·1; at 3 P.M. it was 22°·5; at 5 P.M. 2°·5; and at 10 P.M. as low as 0°·8.

On the 15th the depression was as low as 0°·5, but the active part of the storm had passed; the wind, which had been estimated during the previous night at a velocity of fifteen miles per hour, lowered to seven and to five, the cloud elevated itself so as just

to clear Alta Vista by about 300 feet, and at 8 P.M. the depression of the dew-point was 1°·1.

On the 16th the barometer had risen to 20·632, the temperature increased from 39°, its lowest, to 43°; and the depression of the dew-point to 5°·3.

During these days, and until the 19th, when we left the mountain, the sky was continually cloudy, *i. e.* there was a stratum of cloud at a height greater than 12,000 feet, in addition to the lower stratum at 4000 feet, and this upper bed was eminently hazy and misty. The sun by day, and the moon by night, were seen as pale and watery as they are in the generality of English weather; the autumn had in fact set in on the mountain top, and that locality had lost its specialities as a site for astronomical observations.

On descending the mountain, beyond the N.E. cloud being broken up and scattered, we found that no perceptible change in the weather had been experienced below. On the night of the 14th, when we on the mountain were fearing that the station at Alta Vista would be undermined or be washed away by the torrents of rain, not a drop had fallen on either the N. or S. coast of the island; nay, even a party of visitors who had left us at about 3 P.M. on that day, after the hail-storm, gained the bottom of the mountain without any more wet; and on referring to the Captain's journal on board the yacht, some of the warmest weather of the whole season occurred with him, when we were at the wettest and coldest on the mountain.

The storm then, which, with all its accompaniments, we are justified, by the continual degradation of temperature going on during the whole period of our tenure of Alta Vista, in considering as the commencement of autumn, was confined to the upper regions of the atmosphere and the mountain top, not descending probably below 9000 feet of elevation. This circumstance in itself, viewed as part of a general law, will cause a different rate of decrease of the heat of the atmosphere with altitude, at different seasons of the year; for, in September for instance, we should be stepping from summer below to autumn above; and the actual difference found, will be further increased, if there be an upper stratum of cloud to reflect back the heat of the sun, in the same manner as the lower stratum was found to do in our meteorological journeys. There was, too, such an upper stratum on September 14th and following days; and it appeared also to produce the lowering of the temperature above described, as well as the lessening of the depression of the dew-point. As all these matters are so intimately connected with the theory of refractions and of barometrical altitudes, I subjoin a list of daily differences of mean temperature at the sea-level, and at the height of 10,702 feet as observed:—

August 21	18°·9	September 8	24°·5
August 22	16·7	September 9	22·3
August 23	14·1	September 11	25·3
August 24	17·0	September 12	30·1
September 1	29·2	September 13	29·2
September 2	29·5	September 14	32·5
September 3	27·5	September 15	39·6
September 4	24·6	September 16	36·9
September 5	22·2	September 17	34·1
September 6	23·9		

[Section added during the printing.]

(10.) *Epoch of maximum Summer Heat.*

Most intimately connected with the results just given, must be the epoch of maximum annual heat at the surface of the ground; and attention was called in 1820 by the learned Leopold von Buch, to a very remarkable anomaly in the annual march of temperature for Las Palmas, the capital of Grand Canary; in accordance with which the greatest heat was experienced there in the month of October; and this result seemed all the more noteworthy, as a series of observations at Santa Cruz, in Teneriffe, showed, he thought, no deviation of a similar kind.

On comparing, however, the numbers given by him with the more numerous results since ascertained for other parts of the world, it appeared to us that the Santa Cruz epoch of greatest heat, though earlier than that of Las Palmas, is yet sensibly behind the normal period. The question therefore was then raised,—Does the anomaly still exist, and to what amount? Our own observations extend over too short an interval to settle the point; but some of the instruments which we left behind in Orotava, furnished to us in the first instance by the liberality of Admiral Fitzroy, have since been used with so much intelligence, and observed with daily for a period of thirteen months, by Herr Kreitz, watch-maker of that city, that they have afforded valuable data for the purpose; and the results of his 9 a.m. observations alone are exhibited in the following Table, together with those on which Von Buch depends, viz. 10 years' observations ending, it is believed, in 1816, in Las Palmas, Grand Canary, by Dr. Bandini de Gatti, and 2½ years of observations in Santa Cruz de Teneriffe, by Don Francisco Escolar in 1808, 1809, and 1810. These are reduced, for facility of comparison, to Fahrenheit's scale; not so much, be it remembered, for contrasting their absolute temperatures, which would include instrumental corrections that are unknown, in addition to secular changes, as for the sake of their differences from month to month, which are free from those manifest sources of error.

Months.	Days.	Las Palmas, Grand Canary. Mean of ten days, Reaum.	Mean of ten days, Fahr.	Mean of month, Fahr.	Puerto de Orotava. Mean of ten days, Fahr. 1856.	Mean of ten days, Fahr. 1857.	Mean of month, Fahr.	Santa Cruz de Teneriffe. Mean of ten days, Reaum.	Mean of ten days, Fahr.	Mean of month, Fahr.
		°	°	°	°	°	°	°	°	°
Jan.	1 to 10	13·42	62·19	61·99	.....	61·56	61·06	14·24	64·04	64·11
	11 to 20	13·40	62·15		.....	61·68		14·09	63·70	
	21 to 31	13·17	61·63		.....	59·94		14·48	64·58	
Feb.	1 to 10	14·02	63·54	63·71	.....	59·59	60·51	13·60	62·60	63·70
	11 to 20	14·01	63·52		.....	60·43		14·16	63·86	
	21 to 28	14·25	64·06		.....	61·51		14·51	64·65	
March	1 to 10	14·42	64·44	64·75	.....	61·08	62·95	15·41	66·67	66·79
	11 to 20	14·46	64·54		.....	62·95		15·54	66·96	
	21 to 31	14·79	65·28		.....	64·83		15·44	66·74	
April	1 to 10	15·14	66·06	66·31	.....	68·38	67·69	15·59	67·08	67·43
	11 to 20	15·32	66·47		.....	67·30		15·88	67·73	
	21 to 30	15·29	66·40		.....	67·38		15·77	67·48	
May	1 to 10	15·80	67·55	68·23	.....	70·69	70·62	16·69	69·55	71·85
	11 to 20	16·20	68·45		.....	70·22		17·81	72·07	
	21 to 31	16·30	68·68		.....	70·94		18·64	73·94	
June	1 to 10	16·53	69·19	69·99	.....	73·00	74·33	18·28	73·13	73·89
	11 to 20	16·95	70·14		.....	73·44		18·52	73·67	
	21 to 30	17·17	70·63		.....	76·54		19·05	74·86	
July	1 to 10	17·98	72·46	73·63	.....	75·47	76·65	19·62	76·14	77·20
	11 to 20	18·71	74·10		.....	76·48		20·18	77·40	
	21 to 31	18·82	74·34		.....	78·01		20·47	78·06	
Aug.	1 to 10	19·43	75·72	76·21	.....	76·35	76·44	20·94	79·12	78·67
	11 to 20	19·65	76·21		.....	76·26		21·03	79·32	
	21 to 31	19·87	76·71		75·63	77·82		20·25	77·56	
Sept.	1 to 10	20·95	79·14	80·69	77·56	79·14	76·76	20·52	78·17	77·38
	11 to 20	21·58	80·56		76·18	77·72		19·96	76·91	
	21 to 30	22·38	82·36		75·71	74·24		20·03	77·07	
Oct.	1 to 10	23·42	84·70	84·12	74·02	.....	74·15	19·72	76·37	74·65
	11 to 20	23·54	84·96		73·03	.....		19·02	74·80	
	21 to 31	22·53	82·69		75·41	.....		18·13	72·79	
Nov.	1 to 10	19·98	76·96	71·96	73·13	.....	68·61	18·05	72·61	70·42
	11 to 20	17·32	70·97		68·41	.....		17·08	70·43	
	21 to 30	15·98	67·96		64·30	.....		16·10	68·22	
Dec.	1 to 10	14·42	64·44	63·33	69·84	.....	66·09	15·99	67·98	66·21
	11 to 20	13·72	62·87		66·19	.....		15·37	66·58	
	21 to 31	13·64	62·69		62·25	.....		14·26	64·08	
Mean of year				70·41			69·65			71·02

From this Table then we may gather, that while the epochs of *minimum* temperature for the three places are nearly normal, viz. January 20, February 5, and February 1, the times of *maximum* are October 12, September 5, and August 18; all of them too late, and Las Palmas most notably so. Their *mean* temperatures, however, do not differ much, and Las Palmas, it is worthy of remark, is not the highest of them; but their differences of semi-annual extremes, or 22°·13, 16°·25, and 14°·97, are extremely discordant, and increase continually with an expressive "continental" character, so to speak, or in remarkable accordance with the actual retardation of their summer waves of heat; a circumstance which would have been exactly reversed, if the drag had resulted from the presence of proportionate depths of badly conducting matter, as with earth-thermometers.

The case is therefore altogether most deserving of further inquiry, which, to be successful, must be prefaced by more observations, not only at many different points in the Canarian Archipelago, but at several levels in the atmosphere; for on the different superimposed currents of air, and their respective strata of cloud, it is very evident that a large part of the anomalies of terrestrial-surface climate most intimately depend.

(11.) *Tidal Observations.*

The exposed condition of the Santa Cruz beach offered more difficulties to carrying on tide observations than had been expected, or than I should have been able to overcome, but for the warm cooperation of Mr. Lewis Hamilton, and more particularly of Don Francisco Aguilar, the Engineer of the Mole, who being engaged on some repairs of that structure, kindly undertook the building of such a vertical trough as should be secure from the severe swell usually prevailing. This tide-gauge was only completed on the day of my leaving Santa Cruz: and I could do little more than admire the regularity of the rise of the rod, though the tide came in with great rollers; test the divisions engraved on it, which proved to be English feet and inches; and arrange for the making of some observations, which the Don most obligingly offered to superintend.

The first point to be inquired into was the probable existence of any hitherto unrecognized anomaly in the tide-wave. To detect any such feature, Don Francisco Aguilar kept up observations at five-minute intervals, from 5 o'clock in the morning of the 13th to 9 o'clock in the evening of the 16th of October, 1856.

On projecting these numerous and, I believe, most carefully registered measures, the tide-wave appeared most satisfactorily single; and on communicating them to Dr. Whewell, he expressed himself perfectly content with their freedom from any feature requiring observations at other instants than about the times of high and low water in the ordinary manner.

Matters were thus far cleared and made ready for the next investigation; but before the requisite instructions could reach Santa Cruz, the alterations of the Mole had reached the part where the tide-gauge stood, and compelled its removal. The authorities were again very obliging in giving their permission to the machine's re-erection at a different spot; but this I was not able to undertake.

The Don's observations, already alluded to, are contained in full in volume 1, and give the following times and heights of low and high water:—

Date.	Time. Mean time, Santa Cruz.	Low-water depth.	High-water height.	Moon's meridian transit, South and North.	Luni-tidal interval.
1856.	h m	ft. inches.	ft. inches.	h m	m
October 12.	17 27	3 6·12?			
	23 42	.....	4 5·00	23 23	−19
13.	5 52	3 11·75			
	12 3	.....	3 10·75	11 49	−14
	18 3	3 10·25			
14.	0 23	.....	4 6·25	0 16	− 7
	6 28	3 11·00			
	12 46	.....	3 11·75	12 43	− 3
	18 51	3 9·50			
15.	1 9	.....	4 3·75	1 11	+ 2
	7 14	3 7·00			
	13 34	.....	3 8·87	13 40	+ 6
	19 30	3 7·50			
16.	1 45	.....	3 8·00	2 10	+25
	8 0	3 2·87			

Projections of the above tides indicate 8 feet 3·25 inches as the amount, and thirteen days twenty-two hours as the epoch of extreme rise and fall, or $12^h\ 4^m$ after the instant of full moon. The minutes thus given, and to some extent the hours also, must be taken only as an accidental result of the numbers employed, but come curiously close to the intervals between the times of high water and the moon's transits as given in the last column of the above Table, where the mean of the whole comes to 1 minute, or with 12 hours added, to $12^h\ 1^m$.

These numbers, on being compared with the only published statement I have been able to meet with of the tide at Teneriffe, appear, by their difference therefrom, to justify some further inquiry into them for scientific purposes, at the same time that their differences *inter se*, at first looking anomalous, but soon proving to be correct, as shown particularly in the semidiurnal differences of the high waters, indicate the accuracy of Don Francisco Aguilar's observations.

A barometer, kindly lent by Admiral Fitzroy, was observed by Mr. Hamilton of Santa Cruz during the above observations, and within half a mile of the place where they were made. The differences were so small, that no attempt has been made to correct the height of the tide for them. At 3 P.M. and 9 P.M., the maximum and minimum nearly of the atmospheric wave, the readings were thus:—

	3 P.M.	9 P.M.
	inches.	inches.
October 13.	30·21	30·23
14.	30·20	30·23
15.	30·22	30·23
16.	30·20	30·23

XXVII. *On Curves of the Third Order.* *By the Rev.* GEORGE SALMON, *Trinity College, Dublin. Communicated by* ARTHUR CAYLEY, *Esq., F.R.S.*

Received May 20,—Read June 17, 1858.

THE following Notes are intended as supplementary to Mr. CAYLEY's Memoir on Curves of the Third Order*.

If in a cubic U we substitute $x+\lambda x'$, $y+\lambda y'$, $z+\lambda z'$ for x', y', z', let the result be written

$$U+3\lambda S+3\lambda^2 P+\lambda^3 U',$$

where S and P are evidently the polar conic and polar line of $x'y'z'$ with respect to the cubic, and

$$3S=x'\frac{dU}{dx}+y'\frac{dU}{dy}+z'\frac{dU}{dz}:\ 3P=x\left(\frac{dU}{dx}\right)'+y\left(\frac{dU}{dy}\right)'+z\left(\frac{dU}{dz}\right)'.$$

In like manner let the result of a similar substitution in H be written

$$H+3\lambda\Sigma+3\lambda^2\Pi+\lambda^3 H',$$

where Σ and Π are the polar conic and polar line of $x'y'z'$, with respect to the Hessian. Then the identical equation which Mr. CAYLEY has given, p. 442, may with advantage be replaced by the following,

$$3(S\Pi-\Sigma P)=H'U-U'H,$$

an equation which can be easily verified by the help of the canonical form

$$U=x^3+y^3+z^3+6lxyz.$$

When $x'y'z'$ is on the curve U, the identical equation just written enables us to write the equation $U=0$ in the form

$$S\Pi-P\Sigma=0,$$

a transformation from which many important consequences may be deduced.

In the first place, the equation shows that the lines P, Π intersect on the cubic; hence the *tangential* of the point $x'y'z$, that is to say, the point where the tangent P meets the cubic again, is the intersection of P with Π, the polar of $x'y'z'$ with regard to the Hessian.

Again, the points of contact of tangents from $x'y'z'$ are known to be the intersections of S with the cubic; and the equation shows that the points in question are the intersections of S, Σ†.

Further, the equation shows that $S=\mu\Sigma$ and $P=\mu\Pi$ (where μ is arbitrary) intersect on the cubic. But the second of these equations is the polar of $x'y'z'$ with respect to the former: hence the cubic may be generated as the locus of the points of contact of tangents from a point $x'y'z'$ to a system of conics passing through four fixed points.

* Philosophical Transactions, 1857, p. 415

† See Mr. CAYLEY's Memoir, p. 443.

Let the conic $S=\mu\Sigma$ break up into two right lines; then $P=\mu\Pi$ obviously passes through the intersection of these lines: this intersection is therefore a point on the cubic and $P-\mu\Pi$ the tangent at it. Hence the four points of contact of tangents to the cubic from $x'y'z'$ form a quadrangle, the three centres of which are on the cubic, and are the three points *co-tangential* with $x'y'z'$, that is to say, having the same tangential*.

Formation of the Equation of the Conic through five consecutive Points of a Cubic.

Mr. CAYLEY has communicated to me an investigation of the equation of the above conic in the case where the cubic is given by the equation

$$x^3+y^3+z^3+6lxyz=0.$$

The investigation of the general case presents no greater difficulty, by the help of the identity with which we commenced.

Since S touches the cubic and P is the common tangent, the general equation of a conic touching U must be of the form $S-\alpha P$ (where $\alpha=Ax+By+Cz$ denotes any right line whatever). But by the identity referred to, the equation of the cubic may be written

$$\Pi(S-\alpha P)=P(\Sigma-\alpha\Pi).$$

Hence the four points where $S-\alpha P$ meets the cubic again are its intersections with $\Sigma-\alpha\Pi$, and if the latter conic pass through $x'y'z'$, the former will pass through three consecutive points of the cubic. But on substituting $x'y'z'$ for xyz, we have $\Sigma'=\Pi'=H'$, and the condition that $\Sigma-\alpha\Pi$ shall pass through $x'y'z'$ is simply $\alpha'=1$.

In order that $S-\alpha P$ may pass through four consecutive points, $\Sigma-\alpha\Pi$ must have P for a tangent at the point $x'y'z'$. Now the tangent to $\Sigma-\alpha\Pi$ (being the polar of $x'y'z'$ with respect to this conic) is

$$2\Pi-\alpha'\Pi-\alpha\Pi',$$

or, since

$$\alpha'=1,\ \Pi'=H',\ \text{is}\ \Pi-\alpha H'.$$

But this quantity must be proportional to P. Hence we have

$$\alpha=\lambda P+\frac{1}{H'}\Pi.$$

The general equation therefore of a conic through four consecutive points is

$$S-\lambda P^2-\frac{1}{H'}P\Pi,$$

and

$$\Sigma-\lambda P\Pi-\frac{1}{H'}\Pi^2$$

passes through the two points where the former conic meets the cubic again. Since these two conics have P for a common tangent, it will be possible, by adding the equations (multiplied by suitable constants), to obtain a result divisible by P, and the quotient will be the line joining the points where the conic meets the cubic again. It

* See Mr. CAYLEY's Memoir, p. 444, and my 'Higher Plane Curves,' p. 134.

is necessary, then, in the first place to determine μ so that $\mu S+\Sigma-\frac{1}{H'}\Pi^2$ may be divisible by P, which we do simply by equating to 0 the discriminant of this equation. It will be observed that $\Sigma-\frac{1}{H'}\Pi^2$ denotes a pair of lines drawn through $x'y'z'$ to touch Σ: hence in the discriminant that part vanishes which is not multiplied by μ; and because these two lines intersect on S, the part multiplied by μ also vanishes. Likewise the coefficient of μ^3 in the discriminant of $\mu S+\Sigma$ vanishes, and the coefficient of μ^2 in the discriminant of $\mu S+\Pi^2$ is the function which Mr. CAYLEY has called Θ*. Hence the discriminant of $\mu S+\Sigma-\frac{1}{H'}\Pi^2$ is simply $\mu^2 H'-\mu^3\frac{\Theta'}{H'}$, and therefore, if $\mu=\frac{\Theta'}{H'^2}$, this conic will break up into two right lines, and we may write

$$\mu S+\Sigma-\frac{1}{H'}\Pi^2=\beta P.$$

By the help of this equation, the equation of the cubic can be transformed from the form

$$\Pi S-P\Sigma=0$$

to the form

$$(\Pi+\mu P)\left(S-\lambda P^2-\frac{1}{H}P\Pi\right)=P^2\left\{\beta-\frac{\mu}{H}\Pi-\lambda(\Pi+\mu P)\right\}.$$

The form of the equation shows that $\Pi+\mu P$ is the tangent at the point of the cubic which is tangential to the given one, and that $\beta-\frac{\mu}{H}\Pi$ passes through the point where that tangent meets the cubic again, or, as we shall call it, through the second tangential of the given point.

The theorem contained in the last equation, viz. "that if a conic pass through four consecutive points of a cubic at $x'y'z'$, the chord joining the remaining points passes through the second tangential of $x'y'z'$," may easily be deduced independently. In fact, if $abc=def$ be the equation of any cubic, any conic $ab=\mu de$ meets the cubic again in two points whose chord $\mu c=f$ passes through the fixed point cf. And hence, as is well known, all conics through four points on a cubic meet the curve again in a chord passing through a fixed point which I call the opposite of the four given points, and which is constructed as follows: Let the line joining the points 1 and 2 meet the curve in a point 5, let the line joining the points 3 and 4 meet the curve in a point 6, then the line joining 5, 6 meets the curve in the point 7 required. Now when 1 and 2, 3 and 4 coincide, the points 5 and 6 both coincide with the tangential of that point, and consequently 7 is the second tangential.

It follows immediately that the conic through five consecutive points meets the curve again in a point which is found by joining the original point to its second tangential, and taking the point where the joining line meets the curve again. We deduce hence at once M. PLÜCKER's determination of the points at which a conic can osculate a cubic in six points. In fact, if the point just determined were to coincide with the

* Third Memoir on Quantics, p. 642.

original point, the first and second tangential should coincide; or in other words, the tangential should be a point of inflexion. There are then twenty-seven conics which can meet a cubic in six consecutive points, and the points of contact are the points of contact of the tangents drawn from the nine points of inflexion.

We return to complete the algebraic solution of the problem to determine the equation of the conic meeting a cubic in five consecutive points at $x'y'z'$, and it is obvious that what remains to be done is to determine λ so that the line

$$\beta-\frac{\mu}{H'}\Pi'-\lambda(\Pi+\mu P)$$

may pass through $x'y'z'$. The only difficulty is to determine the result of substituting $x'y'z'$ in β. Now if we differentiate, with regard to x, y, or z, the equation

$$\mu S+\Sigma-\frac{1}{H'}\Pi'=\beta P,$$

and substitute x', y', z' for x, y, z in the result, we get $\beta'=2\mu$. Hence, since $\Pi'=H'$, $P'=0$, we have

$$\beta'-\frac{\mu}{H'}\Pi'-\lambda(\Pi'+\mu P')=\mu-\lambda H'=0,$$

which determines λ in terms of μ, which has been found already.

The equation, then, of the conic having five-point contact with U is

$$(\Pi+\mu P)\left\{S-\frac{1}{H'}P(\Pi+\mu P)\right\}=P^2\left\{\beta-\frac{\mu}{H'}\Pi-\frac{\mu}{H'}(\Pi+\mu P)\right\}.$$

It appears then that $\Pi+\mu P$, the tangent at the first tangential, is the chord of intersection of the five-point conic with the polar conic S. We are thus also able to construct the five-point conic geometrically, since five points of it are given, namely, the two points of intersection of the tangent at the first tangential with S; the point where the line joining the original point to the second tangential meets the curve again; and of course the original point and its consecutive one.

Working with the equation

$$x^3+y^3+z^3+6lxyz=0,$$

Mr. Cayley has calculated the equation of the five-point conic, and thence the coordinates of the point where it meets the curve again. I shall now form the coordinates of the same point, deriving them from the geometrical construction for that point which I have just given. Let xyz be the coordinates of the point of contact, and XYZ those of its second tangential; then the coordinates of the point required must be

$$\lambda x+\mu X,\ y+\mu Y,\ \lambda z+\mu Z,$$

where

$$\lambda=x(X^2+2lYZ)+y(Y^2+2lZX)+z(Z^2+2lXY)$$
$$\mu=X(x^2+2lyz)\ +Y(y^2+2lzx)\ +Z(z^2+2lxy).$$

I write for abbreviation α, β, γ instead of x^2, y^2, z^2; then the coordinates of the first tangential are

$$x(\beta-\gamma),\quad y(\gamma-\alpha),\quad z(\alpha-\beta);$$

and those of the second tangential

$$X=x(\beta-\gamma)\{\beta(\gamma-\alpha)^2-\gamma(\alpha-\beta)^2\};\ Y=y(\gamma-\alpha)\{\gamma(\alpha-\beta)^2-\alpha(\beta-\gamma)^2\}$$
$$Z=z(\alpha-\beta)\{\alpha(\beta-\gamma)^2-\beta(\gamma-\alpha)^2\}.$$

In calculating the expressions for λ and μ, I have found the following theorems useful. Let

$$(\beta-\gamma)^2+(\gamma-\alpha)^2+(\alpha-\beta)^2=2A,$$
$$\alpha(\beta-\gamma)^2+\beta(\gamma-\alpha)^2+\gamma(\alpha-\beta)^2=B,$$
$$\alpha^2(\beta-\gamma)^2+\beta^2(\gamma-\alpha)^2+\gamma^2(\alpha-\beta)^2=2C,$$
$$(\alpha-\beta)(\beta-\gamma)(\gamma-\alpha)=Q.$$

Then

$$(\beta-\gamma)^4+(\gamma-\alpha)^4+(\alpha-\beta)^4=2A^2,$$
$$\alpha(\beta-\gamma)^4+\beta(\gamma-\alpha)^4+\gamma(\alpha-\beta)^4=AB,$$
$$\alpha^2(\beta-\gamma)^4+\beta^2(\gamma-\alpha)^4+\gamma^2(\alpha-\beta)^4=2AC-Q^2;$$

and if

$$p=\alpha+\beta+\gamma,\quad q=\alpha\beta+\beta\gamma+\gamma\alpha,$$

we shall have

$$(\beta-\gamma)^6+(\gamma-\alpha)^6+(\alpha-\beta)^6=2A^3+3Q^2,$$
$$\alpha(\beta-\gamma)^6+\beta(\gamma-\alpha)^6+\gamma(\alpha-\beta)^6=A^2B+pQ^2,$$
$$\alpha^2(\beta-\gamma)^6+\beta^2(\gamma-\alpha)^6+\gamma^2(\alpha-\beta)^6=2A^2C-(p^2-4q)Q^2,$$

$$(\beta-\gamma)^8+(\gamma-\alpha)^8+(\alpha-\beta)^8=2A^4+8AQ^2,$$
$$\alpha(\beta-\gamma)^8+\beta(\gamma-\alpha)^8+\gamma(\alpha-\beta)^8=A^3B+(2pA+B)Q^2,$$
$$\alpha^2(\beta-\gamma)^8+\beta^2(\gamma-\alpha)^8+\gamma^2(\alpha-\beta)^8=2A^3C+(2qA+2C-A^2)Q^2;$$

while again,

$$(\beta-\gamma)^3+(\gamma-\alpha)^3+(\alpha-\beta)^3=3Q,$$
$$\alpha(\beta-\gamma)^3+\beta(\gamma-\alpha)^3+\gamma(\alpha-\beta)^3=pQ,$$
$$\alpha^2(\beta-\gamma)^3+\beta^2(\gamma-\alpha)^3+\gamma^2(\alpha-\beta)^3=qQ,$$

$$(\beta-\gamma)^5+(\gamma-\alpha)^5+(\alpha-\beta)^5=5AQ,$$
$$\alpha(\beta-\gamma)^5+\beta(\gamma-\alpha)^5+\gamma(\alpha-\beta)^5=(pA+B)Q,$$
$$\alpha^2(\beta-\gamma)^5+\beta^2(\gamma-\alpha)^5+\gamma^2(\alpha-\beta)^5=(qA+2C)Q.$$

By the help of these equations I obtain

$$-\mu=(B-2Alxyz)Q$$
$$\lambda=(B-2Alxyz)A(AC-Q^2).$$

We may of course suppress the common factor $B-2Alxyz$, which, by the help of the equation of the curve $p+6lxyz=0$, is seen to be equivalent to $-9(1+8l^3)x^2y^2z^2$; and the coordinates of the required point are

$$Ax(AC-Q^2)-QX, \quad Ay(AC-Q^2)-Qy, \quad Az(AC-Q^2)-Qz^*.$$

The condition, then, that these coordinates should be the original x, y, z, is $Q=0$. But Q denotes the nine lines joining the points of contact of tangents drawn from the point of inflexion. This, then, coincides with M. PLÜCKER's determination, already referred to, of the points of contact of osculating conics.

Osculating Cubics.

If through eight consecutive points of a cubic several cubics be drawn, these all meet the curve again in a fixed ninth point, which can easily be determined. In fact, if we consider the nine points of intersection of two cubics, the opposite (see page 537) of any four lies on the same conic with the remaining five. For let the equation of one be $AU=BV$ and of the other $CU=DV$, where A, B, C, D represent right lines and U, V conics; then the intersections of UV are points common to both cubics, and AB, CD the opposite points in each cubic. But by combining the equations, we get for the equation of the conic through the remaining five points of intersection $AD=BC$, which passes through the two opposite points. Q. E. D.

The theorem may be otherwise stated in what is easily seen to be an equivalent form: the opposites of any two sets of four out of the nine points of intersection lie in a right line with the ninth.

Now we have already proved that, in the case of four consecutive points, the opposite is the second tangential to the original point. Hence, in the case of eight consecutive points, the point through which all cubics through these meet the curve again, is simply the third tangential of the original point. In other words, at the given point A draw a tangent meeting the curve again in B; at B draw a tangent meeting the curve in C; at C draw a tangent meeting it again in D: then D is the point through which all osculating cubics must pass. If AC meet the curve again in E, it has been already shown that E is the point through which all osculating conics must pass; and it is to be observed that the intersection of AD and BE lies on the cubic.

It may be proposed to determine the points at which it shall be possible to draw cubics osculating the given curve in nine points; or in other words, such that the third tangential D may coincide with the original point A. It is evident that in this case the points E and C will coincide; that therefore the coordinates of E, given at the top of this page, must reduce to X, Y, Z; and it has been proved that the condition that this should happen is

$$A(AC-Q^2)=0.$$

Since A is the sum of three squares, it is evident that $A=0$ can denote no real *locus*.

* These coordinates are of the 25th degree in the original coordinates. Mr. CAYLEY has informed me that Mr. SYLVESTER has established that the degree of the coordinates of every derivative point is necessarily a square number. I am led by induction to believe that in the case of three derivative points in a right line, the sum of the square roots of their degrees taken with proper signs is always cypher.

Also, since $4AC-B^2=3Q^2$, the condition $AC-Q^2=0$ may be written $B^2-Q^2=0$, and breaks up into the factors $B\pm Q=0$, or

$$x^3(y^3-z^3)^2+y^3(z^3-x^3)^2+z^3(x^3-y^3)^2\pm(x^3-y^3)(y^3-z^3)(z^3-x^3)=0,$$

or

$$x^6y^3+y^6z^3+z^6x^3-3x^3y^3z^3=0, \quad \text{and} \quad x^3y^6+y^3z^6+z^3x^6-3x^3y^3z^3=0.$$

Hence there are in general seventy-two real or imaginary points of contact of osculating cubics.

When a point on a cubic is determined such that it is its own third tangential, it, together with its first and second tangential, determines a system of right lines, in terms of which the cubic can be transformed to the new canonical form

$$x^2y+y^2z+z^2x+2mxyz=0,$$

in which form the points of inflexion are determined by the right lines

$$x^3+y^3+z^3-3xyz=0.$$

It may be observed that, according to circumstances, one of the two canonical forms is simpler than the other. Thus for the case $S=0$, when the Hessian is one real and two imaginary lines, the canonical forms are

$$x^2y+y^2z+z^2x=0, \quad \text{and} \quad x^3+y^3+z^3+6xyz=0,$$

the former being the simpler. On the contrary, when the Hessian is three real lines, the form $x^3+y^3+z^3$ is simpler than $x^2y+y^2z+z^2x+2mxyz$, where $m^2=-3$.

XXVII. *On the Magnetic Induction of Crystals.*

By Professor JULIUS PLÜCKER, *of Bonn, F.M.R.S., H.M.R.I.*

Received March 26,—Read April 23, 1857.

INTRODUCTION.

IN repeating Professor FARADAY'S experiments, by which he proved that magnetism is a universal agency of nature, to whose influence all bodies are subject, I observed in the year 1847 some strange anomalies, which I attributed to the peculiar structure of the bodies examined. Thus I was led to examine crystalline substances. Between the two poles of a strong electro-magnet I first suspended a plate of tourmaline, then a plate of calcareous spar; and I remarked that these plates, both taken from a polarizing apparatus, were acted upon in an extraordinary way, not dependent on their exterior shape, but solely on their crystalline structure. Since these, my first observations, I have diligently investigated the magnetism of crystals,—this difficult subject of experimental and mathematical inquiry,—guided, as I was, by the conviction that the study of crystals would advance the theory of magnetism as it did previously the theory of light.

The experimental results relating to crystals of the different systems, which, in common with Professor BEER, I have hitherto obtained, are partly published in POGGENDORFF'S 'Annalen.' My intention here is not to complete the series of these results. In order to discover the true law of nature, I thought it more important to select, out of the great number of examined crystals, a few proper to be subjected to a closer examination: I chose red ferridcyanide of potassium, sulphate of zinc, and formiate of copper.

I had proposed in the earliest period of these researches an empirical law, intended to connect all observations concerning extraordinary magnetic action exerted on crystals not belonging to the tesseral system. This law, modified subsequently according to new facts observed by Professor FARADAY and myself, does hold with regard to uniaxal crystals having one principal crystallographic axis. Indeed such a crystal, like tourmaline and calcareous spar, when freely oscillating between the two poles, is directed by them exactly in the same way as if the forces resulting from the magnetic action on each particle of the crystal acted upon a fixed line within the crystal—its magnetic axis,—this axis being always forced either into the axial or into the equatorial plane. These conditions will be satisfied by conceiving the least particles of the crystal to be small magnetic needles, becoming magnetic by induction. Crystals of a more complicated structure, like those above mentioned, could not be brought under the same law; for these therefore I supposed *generally* two such magnetic axes. But here I became convinced that the proposed law does not hold when such crystals are examined in all

directions, and not solely along peculiar ones. Hence nearly two years ago I finally abandoned an hypothesis against which serious doubts had for a long time arisen. For the hypothesis of one or two axes acted upon by the magnet, I substituted another similar hypothesis. In the case of uniaxal crystals, I now conceived an ellipsoid of revolution, consisting of an amorphous paramagnetic or diamagnetic substance, and having within the crystal its principal axis coincident with the principal crystallographic axis. It is easy to verify, that both crystal and ellipsoid, the poles of the magnet not being too near one another, will be directed between them exactly in the same way. In the generalization, an ellipsoid with three unequal axes, having within the crystal a determined direction, must be substituted for the ellipsoid of revolution. In this hypothesis too, we meet with magnetic axes. In the case of uniaxal crystals, the direction I formerly denoted by "magnetic axis" may also be defined as the direction within the crystal round which there is no extraordinary magnetic action. In the general case we get two such directions, which we shall also call "*magnetic axes*," using this name in a different sense from that in which it was employed before. A crystal suspended along either of the two magnetic axes is acted upon like an amorphous body.

According to observation, a crystal under favourable circumstances is directed in the same way as the smallest of its fragments. Hence, according to our new hypothesis, the direction which each of its particles would take, when freely oscillating under the influence of a magnet, may be regarded as determined by an auxiliary ellipsoid. A quite analogous case is that of an amorphous ellipsoid of iron, for instance, with three unequal axes, acted upon by an infinitely distant pole. Here also, according to POISSON's theory, we meet with an auxiliary ellipsoid upon which the pointing of the given one depends. The mode of verifying the existence of such an auxiliary ellipsoid, as well as the laws immediately resulting from it, is exactly the same in both cases. This double verification had the fullest, I may say, an unexpected success. I first proceed to the investigation of the case of POISSON's ellipsoid. Starting from a beautiful theorem lately published by Professor BEER, I was enabled to deduce immediately the analytical expressions, which subsequently I verified in the experimental way. I think this inquiry, in which too I enjoyed Professor BEER's valuable cooperation, will contribute to familiarize experimentalists more and more with the admirable theory, too long neglected, of the French mathematician.

The curious magnetic phenomena I first observed in crystals ten years ago being thus supported by an analytical theory, and the numerical results derived from this theory confirmed by new series of experiments, I take the liberty to lay before the Royal Society an account of my researches. According to the theory of the magnetism of crystals I now propose, the magnetic induction within a crystal is, like the elasticity of the luminiferous ether, determined by means of an auxiliary ellipsoid, which in both cases is similarly placed within the crystal. In both cases there are two fixed directions within it, the two *optic axes* along which there is no double refraction, and the two *magnetic axes*, round which there is no extraordinary magnetic induction. By means of

the two optic axes you may obtain the direction of any wave of light entering the crystal, its plane of polarization, and its velocity of propagation. By means of the two magnetic axes, you may obtain, using analytical expressions of nearly the same form, the couple of magnetic forces acting upon a crystal, when suspended between the two poles along any direction whatever, the position of the crystal, and the law of its oscillations*.

I. *On the direction which biaxial crystals assume when suspended between the two poles along different lines, having a determined position with regard to the primitive form of such crystals.*

1. In all the observations I shall describe in this section I made use of a large electro-magnet, excited by six of GROVE's elements, whose pointed poles were at a distance from each other of 1·6 inch. The crystals, oscillating in the horizontal plane which passes through both poles, and equally distant from these poles, were attached to the double cocoon thread of the torsion balance by means of a hoop, without any other support.

2. *Red ferridcyanide of potassium* ($3K\overline{C}y+Fe\overline{C}y^3$) is paramagnetic. I observed, in the year 1847, that any fragment of this salt, freely suspended between the two poles of an

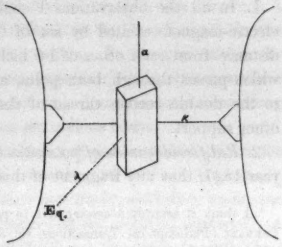
* I think it scarcely necessary here to prove that the theoretical views imputed to me by Professor TYNDALL (Philosophical Transactions, vol. cxlv. p. 2) are not mine, and never have been mine. I never ascribed the phenomena, first observed by myself, to a new force acting upon an ideal line, like the optic axis, quite independent of the paramagnetic condition of the mass of the crystal. Convinced, as I was from the beginning, that there ought to be analogies between the optic and magnetic properties of crystals, I never sought the reason for it anywhere else but in the influence of the crystalline structure on both the luminiferous ether and the magnetic induction. I no more intended to imply a real repulsion or attraction of the optic axes, than the celebrated French philosopher, when he said a beam of light in positive crystals was attracted, in negative ones was repelled, intended to announce a mysterious action emanating in fact from these axes. Such expressions are intended to describe a newly observed fact, but not theoretical views. So also the true meaning of the German words, translated thus, "independent of the paramagnetic or diamagnetic condition of the mass of the crystal," is only this, "whether the mass of the crystal (tourmaline and calcareous spar) be paramagnetic or diamagnetic, the direction of the axis is the same." If, notwithstanding these remarks, there should remain any doubt whatever, I can refer to a paper sent to the Haarlem Society, December 1849, before other philosophers, except Professor FARADAY, had published anything about the magnetic induction of crystals. Starting from mechanical principles, I communicated in this paper a mathematical explanation of what I had observed, for instance, in the case of tourmaline, conceiving this crystal to consist of an infinite number of infinitely small needles, becoming paramagnetic by induction, and being all perpendicular to its axis (see POGGENDORFF's Annalen, lxxxvi. p. 1). The physical conditions of the question, as there stated, seem to be the same as those which Professor TYNDALL has also adopted in his memoir (p. 45). And though I have recently found reason to modify them, yet there is no trace to be found of the supposition imputed to myself, nor even of "the supposition that the assuming of the axial position proved a body to be magnetic, while the assuming of the equatorial position proved a body to be diamagnetic" (p. 13). When there is an analytical expression, representing the resulting action exerted on a body, now attracted, now repelled, according to distance, it is in most cases mathematically legitimate to speak of two "conflicting forces," by dividing the whole expression into two members, one of which represents an attractive, the other a repulsive force.

electro-magnet, does not point like an amorphous paramagnetic body. The poles being not too near one another, the direction the fragment takes does not depend on its exterior form, but solely on its interior crystalline structure. On account of this strong extraordinary magnetic action, the salt above mentioned appears to be peculiarly fit for exhibiting the phenomena and the laws of this action; the larger the crystals you obtain of this salt, the more easily they may be cut and worked.

We may regard a right prism with a rhombic base as the primitive form of our salt*. There are three crystallographic axes perpendicular to each other, the axis of the prism (α), the shorter diagonal of its base ($\varkappa$), and the longer one (λ).

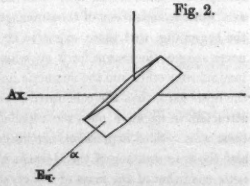
3. A crystal of ferridcyanide of potassium, suspended between the two poles in such a manner that its axis α becomes vertical and therefore its base λ horizontal, sets with energy $\varkappa$ axially (fig. 1). This axis $\varkappa$ remains similarly directed even when we reduce the original prism to a plate, by taking away its obtuse edges. Such a plate appears to be repelled by the two poles like a diamagnetic body, while a plate cut out of the same prism by grinding down its acute edges will be directed, the mode of suspension remaining the same, like a paramagnetic body, as in fact it is.

Fig. 1.



The same prism, suspended in such a manner that its axis α may oscillate between the two poles in the horizontal plane, points equatorially, and seems to be repelled by the poles like a diamagnetic body. We can use in this experiment any natural prism with its summits, whose longest dimension is five or six times greater than its thickness; we may use also a small needle twenty or thirty times as long as it is thick†. In all these cases the oscillating salt finds its position of stable equilibrium by setting itself equatorially. When we reduce the oscillating prism to a plate, by diminishing the dimension of its axis, such a plate, the axis α remaining horizontal, will point axially like an amorphous paramagnetic body.

Fig. 2.

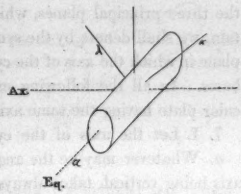


* The primitive form of the salt is disputed. According to the prevalent opinion, we admitted, Professor Beer and myself, in a paper published some years ago, the clinorhombic system, not without some hesitation, as this opinion was neither supported by its magnetic nor its optic properties. I afterwards adopted, in conformity with the new measures recently made by M. Schabus of Vienna, the rhombic system. But again, Nörremberg's admirable new arrangement of Amici's polarizing microscope showing a minute difference between the two systems of rings round the optic axes, not seen in the original apparatus, the question is more doubtful than before.

† Not knowing therefore the extraordinary magnetic action, one would be inclined to range our crystals among diamagnetic bodies, as really has been done.

4. When, always on the supposition of the axis α oscillating horizontally, the shorter diagonal of the rhombic base is vertical, the longer one points axially; when the longer one is vertical, the shorter one points axially. Hence, when any fragment of ferridcyanide of potassium is brought between the two poles, rotating round any one of its three crystallographic axes α, $\varkappa$, λ, this axis being vertical, one of the two remaining axes points axially, and consequently the other equatorially. There are not within the crystal any three other directions enjoying the same property. On this account the three crystallographic axes may also, in the case of our salt, be called *the three axes of paramagnetic induction.* You may distinguish these three axes according to the strength of paramagnetic induction, this induction being in the present case *greatest* along $\varkappa$, *mean* along λ, and *least* along α.

Fig. 3.



5. When, 1st, we cut out of a crystal a cylinder with a circular base, whose axis is α, we may expect, that such a cylinder horizontally suspended will, when turned round its horizontal axis, retain in all its positions the *equatorial* direction (fig. 3). But the directing power emanating from the poles is not the same in the different positions of the rotating cylinder; it is greatest when $\varkappa$ is horizontal and λ vertical; it is least when λ is horizontal and $\varkappa$ vertical. While the cylinder rotates from the first to the second position, this power gradually diminishes.

When, 2nd, we cut out of the same crystal a cylinder whose axis coincides with the shorter diagonal $\varkappa$, such a cylinder, however you may turn it round its axis, supposed horizontal, will always point *axially*. The position agrees with the paramagnetic condition of its substance. But, contrary to this condition, it retains invariably the same position, when, by diminishing its axis, the cylinder is transformed into a circular plate (fig. 4). Such a plate is repelled by the poles with different energy, this energy being greatest when α, and least when λ oscillates horizontally.

Fig. 4.

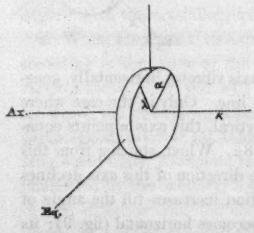


Fig. 5.

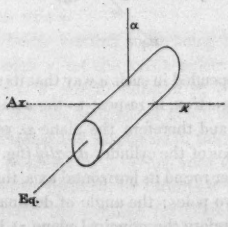
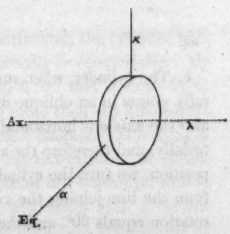


Fig. 6.



When, 3rd, we cut out of the crystal a circular cylinder with its axis parallel to λ, such a cylinder, when horizontally suspended between the two poles, points either equa-

torially (fig. 5) when α, or axially when $\varkappa$ is vertical. When brought, by turning it round the horizontal axis λ, from the first position to the second, its directive power at first diminishes, till in a certain position it quite *vanishes*; and finally, when the cylinder has passed through this intermediate position, reappears, and increases till the cylinder reaches the second position. The cylinder, when setting its axis equatorially, is directed contrary to the paramagnetic condition of its substance; when axially, in conformity with it. When, as before, we reduce the cylinder to a circular plate, the axis remaining the same, the change of direction, by turning the plate round its horizontal axis, takes place in the same way. But then in the first position the cylinder is directed like a common paramagnetic body, in the second position (fig. 6) like a diamagnetic body.

6. We shall now describe the results obtained by operating with circular cylinders cut out of crystals of ferridcyanide of potassium, in such a way that their axis lies in one of the three principal planes, which, according to the two crystallographic axes they contain, we shall denote by the symbols $\alpha\varkappa$, $\alpha\lambda$, $\varkappa\lambda$. The axis perpendicular to the principal plane in which the axis of the cylinder lies, may be marked, before experimenting, on its bases. In all the following experiments we can replace the circular cylinder by a circular plate having the same axis.

7. I. Let the axis of the cylinder lie in the plane $\varkappa\lambda$, forming with $\varkappa$ any angle ϱ.

a. Whatever may be the angle ϱ, the cylinder, when oscillating round its axis, this axis being vertical, takes always such a position that the plane containing the axes $\varkappa$ and λ becomes axial, the axis α *equatorial* (fig. 7).

Fig. 7.

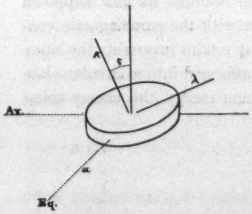


Fig. 8.

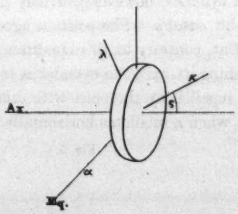
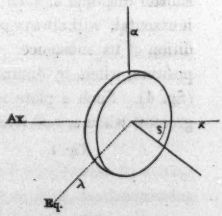


Fig. 9.



b. The cylinder, when suspended in such a way that its axis vibrates horizontally, generally points in an oblique direction, in respect to the axial line. Only in the case where also the axis α is horizontal and therefore the plane $\varkappa\lambda$ vertical, this axis α points equatorially, and therefore the axis of the cylinder *axially* (fig. 8). When, starting from this position, we turn the cylinder round its horizontal axis, the direction of this axis declines from the line joining the two poles; the angle of declination increases till the angle of rotation equals 90°, and therefore the principal plane $\varkappa\lambda$ becomes horizontal (fig. 9); its maximum is ϱ. When the rotation still continues, the axis of the cylinder returns towards the axial line, where it arrives again after a rotation of 180°. From 180° to 360° the

same deviation takes place in the same way on the other side of the axial line. Hence, during an entire revolution of the cylinder round its horizontal axis, this axis passes twice through the *axial* line joining the two poles.

8. II. Let the axis of the circular cylinder lie in the principal plane $\alpha\lambda$, making with the crystallographic axis α any angle σ.

a. Whatever may be the angle σ, the cylinder, when oscillating round its axis, this axis being vertical, assumes always such a position that the vertical plane containing the axes α and λ becomes equatorial, the axis $\varkappa$ *axial* (fig. 10).

Fig. 10.

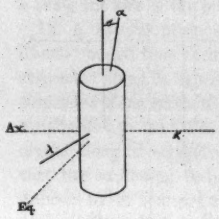


Fig. 11.

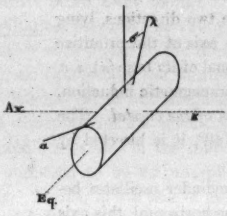
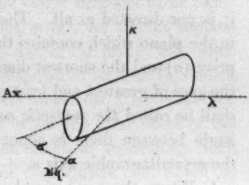


Fig. 12.



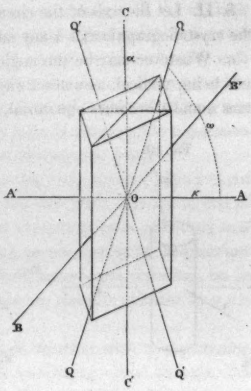
b. When suspended in such a way that its axis is horizontal, the cylinder sets it generally neither axially nor equatorially. When it rotates round its horizontal axis, the angle of deviation from the equatorial line varies in a way similar to that in which in the former case the angle of deviation from the axial line varied. There are two positions of the rotating cylinder where its axis is directed *equatorially*. In this case the plane $\alpha\lambda$ becomes vertical (fig. 11). The maximum of the angle of deviation from the equatorial line equals σ, and in this case the plane $\alpha\lambda$ is horizontal (fig. 12). During an entire revolution of the circular cylinder round its horizontal axis, this axis passes twice through the *equatorial* line.

9. III. Let the axis of the circular cylinder lie in the principal plane $\alpha\varkappa$, making any angle τ with the crystallographic axis $\varkappa$.

a. When suspended, its axis being vertical and λ being horizontal, the cylinder will, according to the value of the angle τ, set the axis λ *either axially or equatorially*. By varying the angle τ you will find a certain value of it, which we may denote by ω, for which the circular cylinder will not be directed at all, no more than any amorphous paramagnetic body of the same shape and suspended in the same manner. The angle ω, after some trials, was found to be about 70°. When such a circular cylinder (or plate), unaffected by the magnet, is gently inclined, by turning it round the horizontal axis λ, in one direction and the contrary, the cylinder (or plate) will again take a certain direction; passing through the indifferent state, it will rotate round the vertical line of suspension through an angle of 90°. When $\tau<\omega$, the axis λ points axially; when $\tau>\omega$, equatorially. The directive power of the poles has its two maxima at $\tau=0$ and $\tau=90°$.

From $\tau=0$ till $\tau=\omega$ it gradually decreases, and finally altogether disappears; from $\tau=\omega$ till $\tau=90°$ it increases again.

Fig. 13.



The angle ω may be taken on either side of the axis $\varkappa$. Hence there are, within crystallized ferridcyanide of potassium, two different directions (QQ and Q'Q', fig. 13), enjoying each the property that the crystal, when suspended along it between the two poles of a magnet, is acted upon like an amorphous paramagnetic body. It merely points in conformity with its exterior shape; when symmetric round its axis of suspension, it is not directed at all. These two directions, lying in the plane which contains the axis of the primitive prism (α) and the shortest diagonal of its base ($\varkappa$), *i. e.* the axes of greatest and least paramagnetic induction, shall be called *the magnetic axes of the crystal.* The angle between them is about 140°, it is bisected by the crystallographic axis $\varkappa$.

b. When the same circular cylinder oscillates between the two poles, its axis being horizontal, this axis points generally in an oblique direction. The cylinder rotating round it, two positions will be found where the axis points either axially or equatorially: it depends upon the value of the angle τ which of these two cases takes place. In this position the crystallographic axis λ lies in the horizontal plane. When the same axis (λ) is vertical, the deviation of the axis of the cylinder from the equatorial or axial line is a maximum, the angle between this axis and the axial line being τ. Between the two mentioned cases, where the axis of the rotating cylinder, according to the value of τ, passes either through the axial or equatorial line, there ought to be an intermediate case, in which the rotating cylinder passes through such a position that the directing power emanating from the poles becomes *uncertain.* It takes place if τ equals about 20° ($=90-\omega$); then the magnetic axis passes through the vertical line. Hence, when the angle τ varies from about $-20°$ to 20°, the axis of the rotating cylinder passes through the axial line; when τ varies from about 20° to 160°, the axis passes through the equatorial line. On this passage the directing power emanating from the poles diminishes when we approach to the intermediate case, where it is zero.

10. In looking over the above-described results obtained by operating on prisms, cylinders, and plates cut out of crystallized ferridcyanide of potassium in various directions with regard to the primitive form of this salt, and suspended in different ways, we may easily remark, that all the observed positions of the crystals between the two poles are exactly the same as those of an ellipsoid made from uncrystallized ferridcyanide or any amorphous paramagnetic substance, and suspended along its different diameters. The three axes of this ellipsoid are to be supposed unequal; they are coincident, according to

their length, with the axis of greatest induction ($\varkappa$), the axis of mean induction (λ), and the axis of least induction (α).

11. *Sulphate of Zinc* ($\dot{Z}n\,\ddot{S}$) is a diamagnetic body, showing the extraordinary magnetic action not nearly so strong as the red ferridcyanide of potassium, but strong enough for exhibiting with nicety all the phenomena analogous to those described in the case of the salt before examined. It was especially selected with the intention to examine whether, in regard to the extraordinary magnetic action also, the diamagnetic induction be altogether the contrary of the paramagnetic. This was fully confirmed by experiment.

We may, as in the former case, denote the three crystallographic axes by α, $\varkappa$, and λ, α being the axis of the primitive prism, $\varkappa$ the shorter, λ the longer diagonal of its base.

12. A natural prism oscillating between the two poles, which we always suppose distant enough from each other with regard to the dimensions of the prism, will, when suspended along its axis (α), set equatorially the shorter diagonal of its base ($\varkappa$); when suspended along its shorter diagonal ($\varkappa$), as well as along the longer one (λ), it sets equatorially its axis (α). These directions remain unchanged when the dimensions of the crystal along its crystallographic axes are, in the different modes of suspending, such that the oscillating body, supposed to be an amorphous diamagnetic one, would be directed in the contrary way. Hence, in the case of our salt, the three crystallographic axes may be called *the axes of diamagnetic induction*, α being the axis of *greatest*, $\varkappa$ of *mean*, and λ of *least* induction.

Fig. 14.

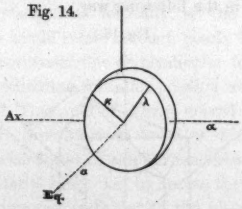


Fig. 15.

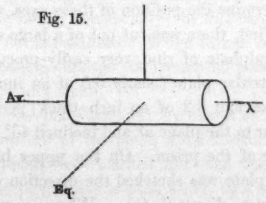


Fig. 16.

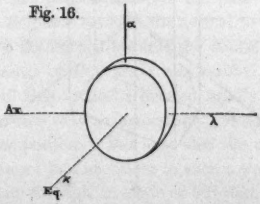
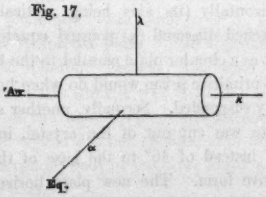


Fig. 17.



13. When we cut out of the crystal a circular plate perpendicular to the axis α, this axis, when oscillating horizontally between the two poles, points equatorially (fig. 14), as in the case of an amorphous paramagnetic body. The directing power emanating from the poles is a maximum if $\varkappa$, a minimum if λ be vertical.

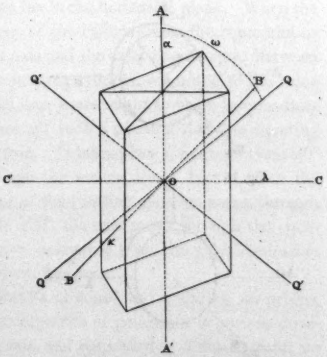
A circular cylinder, whose axis coincides with the longer diagonal (λ), when oscillating horizontally between the poles, sets its axis axially (fig. 15), as an amorphous paramagnetic body of the same shape would do. The directive power is a maximum if $\varkappa$, a minimum if α be vertical.

A circular plate, as well as a circular cylinder, whose axes coincide with the shorter diagonal ($\varkappa$), when suspended with their axes horizontal, set these axes, when rotating round them, either axially or equatorially (figs. 16, 17). There is an intermediate case where no sensible extraordinary magnetic action is observed.

14. A circular cylinder, which also, by diminishing the length of its axis, may be reduced to a circular plate, if its axis do not coincide with one of the three crystallographic axes (α), ($\varkappa$), (λ), points generally obliquely when oscillating with its axis horizontal. It passes, when rotating round its horizontal axis, either through the axial or through the equatorial position. The first case always takes place if its axis lie in the plane $\varkappa\lambda$, the second if it lie in the plane $\alpha\varkappa$. But if the axis lie in the plane $\alpha\lambda$, according to the angles between it and the two axes α, λ, the rotating cylinder passes either through the axial or through the equatorial position.

15. The experiments just described establish the existence, within a diamagnetic crystal also, of two directions, having the property, that the crystal, when suspended along them, is not acted upon by the magnet in an extraordinary way. We may call these directions, as we did in the former case, *the magnetic axes of the crystal.* In order to determine the position of these axes, we proceeded in the following way.

Fig. 18.



First, there was cut out of a large crystal of sulphate of zinc, very easily procurable, a circular plate (nearly 0·5 of an inch diameter and 0·2 of an inch thick) perpendicular to the plane $\alpha\lambda$ and inclined 45° to the base of the prism. On the upper base of the plate was sketched the direction of the shorter diagonal ($\varkappa$). When suspended horizontally (its axis being vertical), the sketched diagonal ($\varkappa$) pointed equatorially, just as a circular plate parallel to the base of the primitive prism would do when horizontally suspended. Secondly, another similar plate was cut out of the crystal, inclined 50° instead of 45° to the base of the primitive form. The new plate horizontally suspended set the shorter diagonal ($\varkappa$) axially. Hence, according to these observations, the angle, with which an indifferent circular plate may be obtained, is between 45° and 50°. It would be difficult to get by this process with certainty closer limits, including the value of this angle. Therefore, the angle between the two magnetic axes

is about 95°, and is bisected by the axis of the primitive prism; these axes lie in the plane containing the *acute* edges of this prism (fig. 18).

16. Let us conceive an ellipsoid of amorphous sulphate of zinc or another diamagnetic substance, having within the crystal of this salt its three unequal axes, according to their length, directed along α, $\varkappa$, λ. The positions which the crystal assumes in all the above described modes of suspension, will be imitated by such an ellipsoid when suspended along its corresponding diameters.

17. *Formiate of copper* ($\dot{C}u\,\dddot{F}o$).—We join to the two examined salts belonging to the same system, one of them being paramagnetic, the other diamagnetic, a third salt, whose primitive form is an oblique prism. There is a plane of symmetry passing through the axis of the prism and the longer diagonal of its rhombic base. The inclination of the axis to the base is 78° 55′; the angles between the lateral faces differ 52′ from a right angle (Heusser): the plane of the base is one of perfect cleavage. This salt, easily crystallizing in large and homogeneous crystals, is paramagnetic, and shows very distinctly the extraordinary magnetic action.

18. At first natural crystals were examined, whose exterior shape had been varied by cleaving them parallel to the base. A horizontal plate bounded by cleavage planes set the symmetrical plane, which, being perpendicular to it, was marked on its upper base, exactly equatorially, even then, when this position did not agree with the position of a similar plate consisting of an amorphous paramagnetic substance. Our plate, when suspended vertically, set the cleavage plane *nearly* equatorially; in this case the plate would rotate through nearly 90°, if it were not crystallized. When turned round the horizontal line perpendicular to its bases, it passed through the equatorial position, its declination from this position remaining always very small.

19. Then, out of a large crystal was cut a circular plate bounded by planes of symmetry, three times as broad as thick. On the surface of the plate, when horizontally suspended and in equilibrium between the two poles, were marked the axial and the equatorial line. Let us denote these two lines, perpendicular to each other, by a and c, the line perpendicular to the plate being denoted by b. The angle within the symmetric plane between the normal to the cleavage plane and a was found to be 3°, taken from the normal towards the obtuse angles of the symmetric plane. The approximate measure of this angle was verified afterwards on different crystals. The same plate oscillating vertically pointed axially when c, equatorially when a was vertical. In the first case only an amorphous paramagnetic body of the same shape would assume the same position. But here also the position of the crystal did not change, after having changed its dimensions in such a way that an amorphous body of the same shape would rotate through an angle of 90° round the vertical axis.

20. The last series of experiments may be described thus: the crystal

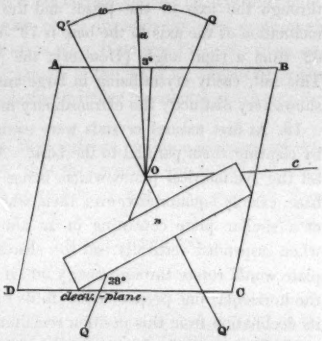
When suspended along a sets axially b;
When suspended along b sets axially a;
When suspended along c sets axially a.

Hence there is proved here also the existence of *three axes of paramagnetic induction*, enjoying the property, that the crystal, when vertically suspended along any one of them, sets one of the remaining two axes axially, the other equatorially. In the case of our salt, the normal to the plane of symmetry is the axis of *mean* induction (b). The axes of *greatest* and *least* induction, (a) and (c), both lie in the plane of symmetry, the first forming an angle of 3° with the normal to the cleavage plane.

We may again conceive an ellipsoid consisting of an amorphous paramagnetic substance, having three unequal axes coincident, according to their length, with a, b, c. Then, in all the different modes of suspension, the crystal will be directed like such an ellipsoid.

21. The *two magnetic axes* are to be sought for within the plane of symmetry containing the greatest and the least axis of induction (a), (c). Therefore a circular plate was prepared, with a diameter of nearly 0·3 of an inch, bounded by planes perpendicular to the symmetric plane ABCD (fig. 19), and inclined to the cleavage plane (the base DC of the primitive oblique prism) 22½°. Horizontally oscillating, this plate set the plane of symmetry, marked by a line on its upper base, equatorially, as a plate bounded by cleavage planes does. After some trials we prepared a similar plate, II., substituting only an angle of 28° for the above angle of 22½°. Such a plate, horizontally oscillating, was not sensibly directed by the poles. Hence the two magnetic axes, QQ and Q′Q′, of formiate of copper, lie in the symmetric plane, including an angle of about 50°, bisected by the above determined axis of greatest induction (a).

Fig. 19.



II. *On finite ellipsoids influenced by an infinitely distant pole.*

22. We have shown that a natural prism of ferridcyanide of potassium, for instance, oscillating between the two poles of a magnet, is kept by them in a fixed position, dependent solely upon the direction of its crystallographic axes with regard to the axis of suspension. It will invariably retain the same position, whatever part we may take away from it, whatever the shape of the remaining fragment may become. From this fact we may conclude that, in the case of this salt, the particles of the influenced crystal do not act sensibly on each other, and hence deduce that the direction of the whole mass of the crystal is plainly defined by the action upon a single one of its molecular particles. According to the above-described experiments, we may infer too, that such a particle is acted upon like a certain amorphous ellipsoid consisting of the substance of the crystal. Again, the action of a magnetic pole upon a single molecule is throughout

analogous to the action of an infinitely distant pole on an ellipsoid of finite dimensions. In both cases the lines of the inductive force are parallel. Thus the solution of the following question coincides with the solution of the question regarding magnecrystallic action:—"To determine the couple of forces acting upon an ellipsoid when influenced by an infinitely distant pole."

23. POISSON gave a complete analytical solution of this question, expressing by means of elliptic functions, which may be calculated in every particular case, the intensity and the direction of the resulting forces, and hence the resulting moment, relating to any given axis of rotation. But the complicated analytical expressions of his formulæ will scarcely allow of deducing from them the law they express. Professor BEER recently succeeded in presenting the results of POISSON's theory in a most simple and elegant way, making use of an auxiliary ellipsoid, whose three axes, $\left(\frac{1}{a}\right)$, $\left(\frac{1}{b}\right)$, $\left(\frac{1}{c}\right)$, are expressed by elliptic integrals.

24. Let this ellipsoid be intersected in the two points M and M′ by the straight line passing through its centre O and the infinitely distant pole. Construct the two planes touching the ellipsoid in M and M′, and perpendiculars from the centre to these planes, intersecting them in the two points P and P′. Let the distances OM and OM′ be denoted by r, the perpendiculars OP and OP′ by p, the angle between OP and OM by ξ. Finally, determine two points E and E′, lying in OP and OP′, on opposite sides of the centre O, whose distance from the centre equals $\frac{1}{rp}$. Now conceive two ellipsoids, both equal to the given influenced one, and having their axes similarly directed, the first one, with its centre in E, filled with southern, the second, with its centre in E′, filled with northern magnetic fluid. Then the resulting action exerted by the infinitely distant pole, supposed to be a northern one, on the given paramagnetically induced ellipsoid equals a couple of forces, represented by the attraction of the first and the repulsion of the second ellipsoid, both filled with magnetic fluid*.

* The solution given above of POISSON's problem immediately results from Professor BEER's communication, which, as it is short, it is but justice to translate here, merely changing, to avoid error, the notation in some cases.

"Let A, B, C be the semi-axes of an ellipsoid, E, electrically influenced by an electric mass, M, infinitely distant along γ, whose action on the unit of volume, filled with the unit of electricity, is $M\mu$. Let $\mu uu'$ be the attraction or repulsion between two infinitely small volumes, u, u', filled with electricity of the density 1, at a distance equal to unity.

"Construct an auxiliary ellipsoid, whose semi-axes $\frac{1}{a^0}$, $\frac{1}{b^0}$, $\frac{1}{c^0}$ are directed along the semi-axes A, B, C of the influenced conductor. Take

$$\frac{1}{a^{0^2}}=\frac{2}{A^2}\int_0^\pi d\vartheta\int_0^\pi dv\,\frac{\frac{\sin^2\vartheta}{\rho^2}-\frac{\cos^2\vartheta}{A^2}}{\left(\frac{\sin^2\vartheta}{\rho^2}+\frac{\cos^2\vartheta}{A^2}\right)^3}\sin\vartheta,$$

where

$$\frac{1}{\rho^2}=\frac{\cos^2 v}{B^2}+\frac{\sin^2 v}{C^2}.$$

In like manner determine $\frac{1}{b^{0^2}}$ and $\frac{1}{c^{0^2}}$ by replacing A by B and A by C. Let r be the radius vector of the

If the induction of the infinitely distant pole, regarded till now to be paramagnetic, become a diamagnetic one, nothing is changed but the sign of the two forces, the first ellipsoid, with its centre in E, being now filled with northern, the second one, with its centre in E′, with southern magnetic fluid.

25. Denoting the value of each force by φ, the resulting moment of rotation is immediately found to be

$$\frac{2\varphi \sin \xi}{pr}, \text{ or } \frac{2\varphi \tan \xi}{r^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1.)$$

The axis of this moment, which we shall denote by OR, round which the influenced ellipsoid tends to move, is perpendicular to the plane MOP. The two diameters OM and OR, possessing the property of being axes of the ellipse formed by the intersection of the ellipsoid with the plane passing through them, are *two conjugate axes* of the surface; the relation between the two is a reciprocal one. To any diameter, regarded as one of two such axes, corresponds only one conjugate axis. Therefore the axis round which the body tends to revolve is continually changed, if the given ellipsoid under the influence of the infinitely distant pole freely move round its centre. To any one of the three axes of the auxiliary ellipsoid exceptionally corresponds an infinite number of second conjugate axes, lying all in the principal plane perpendicular to it. Hence the influenced ellipsoid will oscillate continually round such an axis if the infinitely distant pole lie in the conjugate principal plane.

26. When the influenced ellipsoid is only free to rotate round a vertical line passing through its centre—we shall always suppose the infinitely distant pole to lie in the

auxiliary ellipsoid along γ, and construct at its extremity the tangent plane. Let p be the length of the perpendicular from the centre on this plane, and γ' its direction. Let the influenced ellipsoid E move along γ' through the infinitely small distance $\frac{1}{\pi p}.\sigma$, and denote it in the new position by $E_{,}$. By the two ellipsoids E and E′, two infinitely thin sheets are determined, whose acute edges lie in the curve of intersection of E and $E_{,}$. One of these two sheets, placed towards M, is exterior to E and interior to $E_{,}$; the other, placed oppositely to M, is interior to E and exterior to $E_{,}$. Conceive both sheets filled with electricity of the same density, $\frac{\varkappa}{\mu}\frac{M}{\sigma}$, but of a different kind, the electricity of the second sheet being the same as the electricity of M.

"Such is on the surface of the influenced ellipsoid E the distribution of electricity induced by the infinitely distant mass M."—POGGENDORFF's Annalen, xciv. p. 192.

It is well known that the mathematical theory of magnetic induction differs from the theory of electrical induction only by a constant, which POISSON denotes by k; this constant being equal to unity in the last case. In order to apply Professor BEER's construction to magnetic induction, we have only to replace the above defined auxiliary ellipsoid by another, whose semi-axes $\frac{1}{a}, \frac{1}{b}, \frac{1}{c}$ are connected with the former semi-axes $\frac{1}{a^0}, \frac{1}{b^0}, \frac{1}{c^0}$ by the following relations:—

$$\frac{1}{a^2}=2\pi(1-k)+k\frac{1}{a^{0^2}}$$

$$\frac{1}{b^2}=2\pi(1-k)+k\frac{1}{b^{0^2}}$$

$$\frac{1}{c^2}=2\pi(1-k)+k\frac{1}{c^{0^2}}.$$

horizontal plane, which therefore contains OM—we may project OP on the horizontal plane, and denote the angle between this projection OP′ and OM by ξ'. Then the moment of rotation round the vertical axis is found to be

$$\frac{2\phi \tan \xi'}{r^2}, \quad \ldots \ldots \ldots \ldots \quad (2.)$$

the radius vector r being always directed towards the pole. The horizontal plane is intersected by the auxiliary ellipsoid in an ellipse passing through M. According to simple geometrical relations, the angle ξ' may be defined also to be, in the horizontal plane, the angle between OM and the perpendicular from the centre O on the straight line touching the ellipse in M.

27. In the case of equilibrium, where the moment of rotation disappears,

$$\tan \xi' = 0.$$

This condition is satisfied if one of the two axes of the ellipse lying in the horizontal diametral plane points towards the infinitely distant pole; if the longer axis does, $\frac{1}{r^2}$ is a maximum, the equilibrium therefore an unstable one; if the shorter axis, $\frac{1}{r^2}$ becomes a minimum, the equilibrium a stable one. Hitherto the induction was supposed to be paramagnetic; if it become a diamagnetic one, the unstable equilibrium becomes stable, and *vice versâ*. If the section in the horizontal plane be a circle, the angle ξ' always equals zero, the ellipsoid, therefore, however turned round its vertical diameter, will not move. Hence, the magnetic pole being always situated in the horizontal plane,

An ellipsoid with three unequal axes, oscillating round any of its diameters, supposed to be vertical, when influenced either paramagnetically or diamagnetically by an infinitely distant pole, will be so directed that the auxiliary ellipsoid sets the shorter axis of its horizontal section either axially or equatorially. The two diameters of the auxiliary ellipsoid, perpendicular to its circular sections, are the two magnetic axes of the influenced ellipsoid.

28. In order to verify these results emanating from POISSON's theory in the case of an ellipsoid with three unequal axes, influenced by an infinitely distant pole, it will be necessary to develop them in the analytical way. The formulæ we shall deduce will find also their immediate application in the case of magnetically induced crystals.

Let us suppose the influenced ellipsoid to rotate round any of its diameters, this diameter being vertical, and the infinitely distant pole lying in the horizontal plane. Its position of equilibrium and the law of its oscillations round the vertical diameter will be determined by the ellipse in which the horizontal plane intersects the auxiliary ellipsoid. This ellipsoid is represented in the ordinary way by the equation

$$a^2x^2 + b^2y^2 + c^2z^2 = 1, \quad \ldots \ldots \ldots \ldots \quad (3.)$$

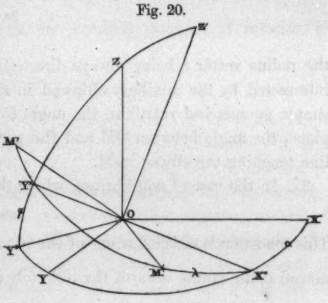
where

$$a^2 > b^2 > c^2.$$

The greatest axis of the influenced and the least of the auxiliary ellipsoid lie along

OX (fig. 20), the mean axis of both ellipsoids along OY, the least axis of the first and the greatest of the second along OZ. We may determine the horizontal plane X′OY′, passing through the common centre of both ellipsoids, by two angles, α and φ; α being the angle between the axis OX and the line OX′ in which the plane XOY is intersected by the plane X′OY′, and φ the angle between the two planes. This determination admits no ambiguity when we conceive the plane XOY to pass from its original position by a double rotation into the horizontal plane X′OY′; rotating first round OZ through the angle α, taken from OX towards OY, till OX coincides with OX′ and OY with a line we shall denote by OY$^{\alpha}$; rotating secondly round OX′ through the angle φ, taken in the plane ZOY$^{\alpha}$, from OY$^{\alpha}$ towards OZ, till OY$^{\alpha}$ coincides with OY′ and OZ with OZ′. The three new axes, OX′, OY′, OZ′, are perpendicular to each other, as the primitive ones are. The equation of the ellipse in the horizontal plane X′OY′, referred to the axes of coordinates OX′ and OY′, is immediately obtained, when in the equation (3.), by means of the following relations,

Fig. 20.



$$x = x' \cos\alpha - y' \sin\alpha \cos\varphi,$$
$$y = x' \sin\alpha + y' \cos\alpha \cos\varphi,$$
$$z = y' \sin\varphi,$$

x, y and z are replaced by x' and y'. It becomes

$$\varrho x'^2 + 2\sigma x'y' + \tau y'^2 = 1, \quad \ldots \ldots \ldots \quad (4.)$$

by putting, for brevity,

$$\left.\begin{aligned} &a^2 \cos^2\alpha + b^2 \sin^2\alpha &&= \varrho \\ &-(a^2 - b^2) \sin\alpha \cos\alpha \cos\varphi &&= \sigma \\ &(a^2 \sin^2\alpha + b^2 \cos^2\alpha) \cos^2\varphi + c^2 \sin^2\varphi &&= \tau. \end{aligned}\right\} \quad \ldots \ldots \quad (5.)$$

Denoting the two semi-axes OM and OM′ of this ellipse by $\frac{1}{a'}$ and $\frac{1}{b'}$, and the two angles, MOX′ and M′OX′, between them and the axis OX′ by λ and $(\lambda + \frac{1}{2}\pi)$, we get the well-known equations—

$$(a'^2 - b'^2)^2 = (\varrho - \tau)^2 + 4\sigma^2, \quad \ldots \ldots \ldots \quad (6.)$$

$$\tan 2\lambda = -\frac{2\sigma}{\varrho - \tau}. \quad \ldots \ldots \ldots \quad (7.)$$

29. From these two equations we may first deduce the following one,

$$(a'^2 - b'^2) = \pm \frac{2\sigma}{\sin 2\lambda},$$

whence, by substitution,

$$(a'^2-b'^2)=\pm(a^2-b^2)\frac{\sin 2\alpha}{\sin 2\lambda}\cos\varphi. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8.)$$

30. Again, the formula (7.) may be expanded thus:—

$$\tan 2\lambda=-\frac{\sin 2\alpha\cos\varphi}{\cos 2\alpha+k\sin^2\varphi}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9.)$$

where

$$k=\frac{a^2\sin^2\alpha+b^2\cos^2\alpha-c^2}{a^2-b^2}=\sin^2\alpha+\frac{b^2-c^2}{a^2-b^2}.$$

Denoting the angle between the two magnetic axes, perpendicular to the circular sections of the auxiliary ellipsoid (3.), by 2ω (fig. 21), we obtain

$$\frac{b^2-c^2}{a^2-b^2}=\tan^2\omega, \qquad \frac{b^2-c^2}{a^2-c^2}=\sin^2\omega, \qquad \frac{a^2-b^2}{a^2-c^2}=\cos^2\omega, \quad . \quad . \quad . \quad . \quad . \quad (10.)$$

whence

$$k=\sin^2\alpha+\tan^2\omega. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11.)$$

Fig. 21.

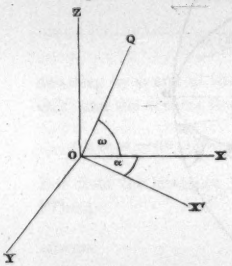


Fig. 22.

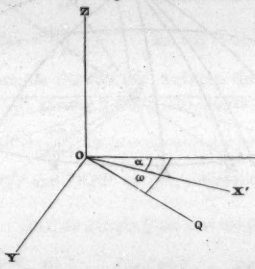
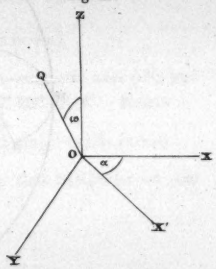


Fig. 23.



31. It will be in some cases more convenient to refer the horizontal intersecting plane to another principal section of the auxiliary ellipsoid. Hitherto we have supposed—and so we shall do again in the following articles—the shortest axis $\frac{1}{a}$, the mean $\frac{1}{b}$, and the longest $\frac{1}{c}$ to coincide with OX, OY, and OZ. Now let $\frac{1}{a}$ fall, as before, on OX, but $\frac{1}{c}$ on OY, and $\frac{1}{b}$ on OZ, and accordingly let α be taken in the plane containing the shortest and the longest axis (fig. 22), from the former towards the latter. In this case b is to be replaced by c, and *vice versâ*; therefore

$$k=\sin^2\alpha-\sin^2\omega. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12.)$$

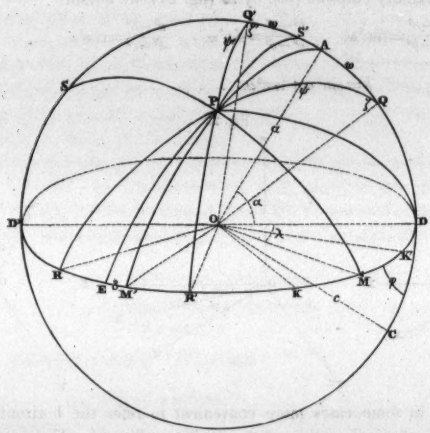
32. When, thirdly, $\frac{1}{a}$ falls on OZ, $\frac{1}{b}$ on OX, and $\frac{1}{c}$ on OY, and accordingly α is taken in the plane YOX (fig. 23), from the mean axis $\frac{1}{b}$ towards the longest $\frac{1}{c}$, we get

$$k=\sin^2\alpha-\cos^2\omega. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (13.)$$

33. By means of the formulæ (9.) and (11.)—(13.), we can determine the position of the influenced ellipsoid, if by the angles α and ϕ its horizontal section be fixed, with regard to any of its three principal planes. The two axes of the elliptic section of the auxiliary ellipsoid in the same horizontal plane, determined both by λ, will point axially and equatorially. The same two axes may be found also by the most simple geometrical construction.

34. Let the axis $\frac{1}{a}$ fall on OA, the axis $\frac{1}{c}$ on OC; let OQ and OQ′ (fig. 24) be the two magnetic axes lying in the plane containing OA and OC, therefore $AQ=AQ'=\omega$.

Fig. 24.



Let DMD′ be the horizontal plane, AD being α and $MDC=\phi$; let P be the pole of this plane, whence OP the vertical axis of suspension. Let OE be the projection of OA on the horizontal plane, OR and OR′ the projections of the two magnetic axes OQ and OQ′. Let OK and OK′ in the same plane be the traces of the two circular sections of the auxiliary ellipsoid, and OM and OM′ the two semi-axes of the horizontal elliptic section, pointing axially and equatorially.

The two semidiameters (OK and OK′) in which any elliptical section of the ellipsoid is intersected by its two circular sections, are both equal to the mean semi-axis $\frac{1}{b}$. The two semidiameters (OR and OR′) of the same elliptical section, perpendicular to OK and OK′, are likewise equal to one another. Hence we shall find the two axes, OM and OM′, of this section, here supposed horizontal, by bisecting the angle RR′ and its supplementary angle.

35. This construction of the two axes OM and OM′ is easy to execute on a given sphere; we may also without difficulty transform it into analytical expressions.

Considering the three rectangular spherical triangles AED, QRD, and Q′R′D, the angle ADE being $\pi-\phi$, we get

$$\left.\begin{aligned}\tan \mathrm{DE} &= -\tan \alpha \cos \phi,\\ \tan \mathrm{DR} &= -\tan (\alpha-\omega) \cos \phi,\\ \tan \mathrm{DR}' &= -\tan (\alpha+\omega) \cos \phi,\end{aligned}\right\} \quad \ldots \ldots \ldots \quad (14.)$$

whence

$$\left.\begin{aligned}\lambda+\pi &= \tfrac{1}{2}(\mathrm{DR}+\mathrm{DR}') = \mathrm{DM}',\\ \delta &= \mathrm{DE}-\mathrm{DM}',\end{aligned}\right\} \quad \ldots \ldots \ldots \quad (15.)$$

denoting by δ the angle between OE, the projection of OA on the horizontal plane, and OM′ pointing within this plane axially or equatorially.

36. The following relations too will afterwards be employed. From the two triangles QRD and Q′R′D, just considered, we deduce also,

$$\cos \mathrm{DR} = -\frac{\cos(\alpha-\omega)}{\sin \psi}, \qquad \sin \mathrm{DR} = \sin \zeta \sin (\alpha-\omega),$$

$$\cos \mathrm{DR}' = -\frac{\cos(\alpha+\omega)}{\sin \psi'}, \qquad \sin \mathrm{DR}' = \sin \zeta' \sin (\alpha+\omega),$$

denoting by ψ and ψ' the angles PQ and PQ′, between the two magnetic axes (OQ and OQ′) and the vertical line OP, and by ζ and ζ' the angles DQP and DQ′P. Hence

$$\sin 2\lambda = -\sin (\mathrm{DR}+\mathrm{DR}') = \frac{\sin \zeta}{\sin \psi} \sin (\alpha-\omega) \cos (\alpha+\omega) + \frac{\sin \zeta'}{\sin \psi} \cos (\alpha-\omega) \sin (\alpha+\omega).$$

But from the triangles DQP and DQ′P we get, remembering that $\mathrm{PDQ} = \frac{1}{2}\pi - \phi$ and $\mathrm{PD} = \frac{1}{2}\pi$,

$$\sin \zeta \sin \psi = \sin \zeta' \sin \psi' = \cos \phi,$$

whence

$$\frac{\sin \zeta}{\sin \psi} = \frac{\sin \zeta'}{\sin \psi} = \sqrt{\frac{\sin \zeta \sin \zeta'}{\sin \psi \sin \psi'}} = \frac{\cos \phi}{\sin \psi \sin \psi'};$$

therefore, expanding the last equation,

$$\sin \psi \sin \psi' = \frac{\sin 2\alpha \cos \phi}{\sin 2\lambda}. \quad \ldots \ldots \ldots \quad (16.)$$

Reverting to the equation (8.), in which here, according to art. (31), b^2 is to be replaced by c^2, we may write it now thus:—

$$(a'^2-b'^2) = (a^2-c^2) \sin \psi \sin \psi'. \quad \ldots \ldots \ldots \quad (17.)$$

37. By means of the angle ω we have determined the position of the influenced ellipsoid: this position, reciprocally, being determined by observation in any particular case, we can find the angle ω. We may use for this purpose the formulæ (9.) and (11.)—(13.). But a simple geometrical consideration will equally lead us to the determination of the value of ω.

The two vertical planes SPM and S′PM′, containing the two axes of the horizontal section, and the two planes QPR and Q′PR′ bisecting them, constitute what is called a

system of four harmonic planes. Such a system is intersected by any plane in four harmonic lines. OS, OS′ and OQ, OQ′ are therefore four harmonic lines, whence the angle 2ω between OQ and OQ′ being bisected by OA,

$$\tan\eta\tan\eta'=\tan^2\omega, \quad \ldots\ldots\ldots\ldots \quad (18.)$$

denoting the angles OS and OS′ by η and η'. Again, in the triangle PDS, observing that $\mathrm{PDS}=\frac{1}{2}\pi-\phi$, $\mathrm{DPS}=\pi-\lambda$, $\mathrm{DS}=\eta+\alpha$, we get

$$\left.\begin{aligned}\tan(\eta+\alpha)&=-\frac{\tan\lambda}{\cos\phi},\\ \text{whence}\qquad \tan(\eta'+\alpha)&=\frac{\cot\lambda}{\cos\phi}.\end{aligned}\right\} \quad \ldots\ldots\ldots\ldots \quad (19.)$$

The position of the horizontally oscillating plane being determined, within the influenced ellipsoid, by the two angles α and ϕ, and the two directions within this plane pointing axially and equatorially by λ, the last two equations furnish the values of η and η', whence, by means of (18.), we obtain the value of ω, and consequently the directions of the two magnetic axes.

38. We have hitherto considered as known the direction of the three axes of the auxiliary ellipsoid. Such is the case in the question of a given ellipsoid, influenced by an infinitely distant magnetic pole, where these three axes are coincident with the three axes of the influenced ellipsoid. But, when treating on the magnetic induction of crystals, we shall meet with questions where the direction of the axes of the auxiliary ellipsoid is to be determined by experiment. If a given ellipsoid be suspended along any diameter, we can find the two axes of the horizontal section of the auxiliary ellipsoid, these axes pointing, one axially, the other equatorially. The new question therefore is a geometrical one, "To determine the three axes of an ellipsoid, knowing the two axes of each of its sections," and may be resolved in the following way.

Let the given influenced ellipsoid revolve round any one of its diameters, supposed to lie in the horizontal plane, and mark in each of its positions the axial as well as the equatorial line. These two lines, two conjugate axes of the auxiliary ellipsoid, will describe during one revolution a conic surface of the third order, containing the three axes of the auxiliary ellipsoid; for these axes will successively pass through the horizontal plane, and then point either axially or horizontally. Hence two such conic surfaces will determine the three axes of the auxiliary ellipsoid.

39. Let any two conjugate axes of the auxiliary ellipsoid be represented by

$$\begin{aligned}x&=gz, & x&=g'z,\\ y&=hz, & y&=h'z,\end{aligned}$$

while this ellipsoid is always represented by

$$a^2x^2+b^2y^2+c^2z^2=1.$$

Then

$$\begin{aligned}gg'+\ \ hh'+1&=0,\\ a^2gg'+b^2hh'+c^2&=0,\end{aligned}$$

whence

$$\left.\begin{aligned} gg' &= \frac{b^2-c^2}{a^2-b^2}=\tan^2\omega, \\ hh' &= -\frac{a^2-c^2}{a^2-b^2}=-\frac{1}{\cos^2\omega} \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (20.)$$

The two conjugate axes, when lying in the above-mentioned conic surface, are contained in a plane passing also through the horizontal diameter round which the given ellipsoid revolves. This diameter being represented by

$$x=mz,$$
$$y=nz,$$

we get, therefore,

$$(g'-g)n+(h-h')m+(gh'-hg')=0.$$

Eliminating g and h' by means of (20.), and putting $\frac{x}{z}$ and $\frac{y}{z}$ instead of g and h, we obtain the following equation:

$$\frac{(nx-my)}{z}\cos^2\omega+\frac{(y-nz)}{x}\sin^2\omega+\frac{x-mz}{y}=0, \quad . \quad . \quad . \quad . \quad (21.)$$

representing the conic surface of the third order.

40. Reverting to the rotation of the influenced ellipsoid, we immediately obtain the instantaneous axis of rotation. The given diameter OM passing, when prolonged, through the infinitely distant pole, and this axis being two conjugate axes of the auxiliary ellipsoid, each of them is determined by the other by means of (20.). Denoting the angles between OM and the three axes of coordinates OX, OY, OZ by μ, ν, ξ, and those between the instantaneous axis of rotation and the three same axes of coordinates by μ', ν', ξ', we have

$$-\frac{\cos\mu\cos\mu'}{\sin^2\omega}=\cos\nu\cos\nu'=-\frac{\cos\xi\cos\xi'}{\cos^2\omega}. \quad . \quad . \quad . \quad . \quad (22.)$$

41. The absolute moment of rotation found to be

$$\frac{2\varphi\tan\xi}{r^3}$$

may easily be expanded: ξ being the angle between the diameter OM passing through M, whose coordinates may be denoted by x, y, z, and the perpendicular to the plane touching the auxiliary ellipsoid in this point, we get by well-known formulæ,

$$\tan^2\xi=[(a^2-b^2)xy]^2+[(a^2-c^2)xz]^2+[(b^2-c^2)yz]^2=(a^2-c^2)^2[x^2y^2\cos^2\omega+x^2z^2+y^2z^2\sin^2\omega],$$

whence

$$\left(\frac{\tan\xi}{r^2}\right)^2=(a^2-c^2)[\cos^2\mu\cos^2\nu\cos^2\omega+\cos^2\mu\cos^2\xi+\cos^2\nu\cos^2\xi\sin^2\omega];$$

and by eliminating $\cos^2\nu$ by means of

$$\cos^2\mu+\cos^2\nu+\cos^2\xi=1,$$

and by reducing,

$$\left(\frac{\tan\xi}{r^2}\right)^2=\tfrac{1}{4}(a^2-c^2)^2[\sin^2 2\mu+\sin^2\omega(\sin^2 2\xi-\sin^2 2\mu)]. \quad . \quad . \quad . \quad . \quad . \quad . \quad (23.)$$

When the infinitely distant pole falls successively within each of the three principal

sections of the auxiliary ellipsoid, the following resulting moments of rotation are obtained:—

$$\varphi(a^2-b^2)\sin 2\mu, \qquad \varphi(a^2-c^2)\sin 2\mu, \qquad \varphi(b^2-c^2)\sin 2\nu.$$

42. Now let us suppose the given ellipsoid to rotate round its vertical diameter, the horizontal plane being determined by any two angles α and ϕ. Let the elliptical section of the auxiliary ellipsoid within the horizontal plane (4.) be represented by

$$a'^2x^2+b'^2y^2=1,$$

its shorter semi-axis $\frac{1}{a}$ lying in the axis of abscissæ. Let r' be the length of the semi-diameter OM of this elliptical section passing, if prolonged, through the infinitely distant pole, and x' and y' the coordinates of its extremity, M. Then

$$\tan\xi'=(a'^2-b'^2)x'y',$$

whence the moment of rotation round the vertical axis

$$\frac{2\varphi\tan\xi'}{r'^2}=2\varphi(a'^2-b'^2)\frac{x'y'}{r'^2}=2\varphi(a'^2-b'^2)\sin\vartheta\cos\vartheta, \quad . \quad . \quad . \quad . \quad . \quad (24.)$$

the angle between the radius vector r' and the shorter axis $\frac{1}{a'}$ being ϑ.

43. The oscillations of the influenced ellipsoid, when infinitely small, may easily be analytically determined. The ellipsoid, supposed to be paramagnetically induced, is in stable equilibrium when the shorter semi-axis $\left(\frac{1}{a'}\right)$ of the elliptical section of the auxiliary ellipsoid within the horizontal plane points towards the infinitely distant pole. When rotated through an infinitely small angle, this angle being the angle ϑ between r' and the axis $\left(\frac{1}{a'}\right)$, the corresponding moment of rotation becomes

$$2\varphi(a'^2-b'^2)\vartheta. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (25.)$$

This expression will remain unchanged when the paramagnetic induction becomes a diamagnetic one; φ becoming, in this case, negative and the longer axis $\left(\frac{1}{b'}\right)$, instead of the shorter $\left(\frac{1}{a'}\right)$, directed towards the infinitely distant pole.

We obtain therefore, in both cases,

$$\frac{d^2\vartheta}{dt^2}=\frac{2\varphi(a'^2-b'^2)}{MK^2}\vartheta,$$

denoting the mass of the influenced ellipsoid by M, and its moment of inertia with regard to the vertical axis by MK^2. Consequently the ellipsoid, under the influence of the infinitely distant pole, oscillates like a common pendulum. Denoting the time of one oscillation by Θ, we get, in the ordinary way, by integration,

$$\Theta^2=\frac{MK^2\pi^2}{2\varphi(a'^2-b'^2)}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (26.)$$

44. When we suppose the three semi-axes A, B, C of the influenced ellipsoid to be successively vertical, the corresponding values of K^2 become

$$\tfrac{1}{5}(B^2+C^2)=K^2_{,}, \quad \tfrac{1}{5}(A^2+C^2)=K^2_{,,}, \quad \tfrac{1}{5}(A^2+B^2)=K^2_{,,,},$$

whence, in the general case, α^0, β^0, γ^0 being the angles between the vertical axis of rotation and the three semi-axes A, B, C,

$$K^2 = K_{\prime}^2 \cos^2 \alpha^0 + K_{\prime\prime}^2 \cos^2 \beta^0 + K_{\prime\prime\prime}^2 \cos^2 \gamma^0.$$

The time corresponding to one oscillation round A, B, C being denoted by $\Theta_{\prime}$, $\Theta_{\prime\prime}$, $\Theta_{\prime\prime\prime}$, we have

$$\left.\begin{aligned} \Theta_{\prime}^2 &= \tfrac{1}{10}\pi^2 \frac{M}{\varphi} \cdot \frac{B^2+C^2}{b^2-c^2}, \\ \Theta_{\prime\prime}^2 &= \tfrac{1}{10}\pi^2 \frac{M}{\varphi} \cdot \frac{A^2+C^2}{a^2-c^2}, \\ \Theta_{\prime\prime\prime}^2 &= \tfrac{1}{10}\pi^2 \frac{M}{\varphi} \cdot \frac{A^2+B^2}{a^2-b^2}. \end{aligned}\right\} \quad \ldots \ldots \ldots \quad (27.)$$

Remembering the relations (10.), we find, by division,

$$\left.\begin{aligned} \frac{\Theta_{\prime\prime}^2}{\Theta_{\prime\prime\prime}^2} &= \frac{A^2+C^2}{A^2+B^2} \cdot \cos^2 \omega, \\ \frac{\Theta_{\prime\prime}^2}{\Theta_{\prime}^2} &= \frac{A^2+C^2}{B^2+C^2} \cdot \sin^2 \omega, \\ \frac{\Theta_{\prime\prime\prime}^2}{\Theta_{\prime}^2} &= \frac{A^2+B^2}{B^2+C^2} \cdot \tan^2 \omega; \end{aligned}\right\} \quad \ldots \ldots \ldots \quad (28.)$$

and likewise, according to (17.),

$$\frac{\Theta_{\prime\prime}^2}{\Theta^2} = \frac{K_{\prime\prime}^2}{K^2} \cdot \frac{a'^2-b'^2}{a^2-c^2} = \frac{K_{\prime\prime}^2}{K^2} \sin\psi \sin\psi', \quad \ldots \ldots \ldots \quad (29.)$$

ψ and ψ' being, as before, the angles between the vertical axis of rotation and the two magnetic axes.

45. Eliminating, finally, ω from any two of the three equations (28.), we obtain

$$\frac{A^2+B^2}{\Theta_{\prime\prime\prime}^2} + \frac{B^2+C^2}{\Theta_{\prime}^2} = \frac{A^2+C^2}{\Theta_{\prime\prime}^2}. \quad \ldots \ldots \ldots \quad (30.)$$

46. With regard to the magnetic induction of crystals, the following geometrical considerations will not appear without some interest.

The auxiliary ellipsoid, whose equation in rectangular coordinates is

$$a^2x^2 + b^2y^2 + c^2z^2 = 1, \quad \ldots \ldots \quad (3.)$$

may be replaced by another one represented by

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} + \frac{z^2}{c^2} = 1. \quad \ldots \ldots \ldots \quad (31.)$$

The new ellipsoid, whose axes are a, b, c, may be called the *first* auxiliary ellipsoid; the ellipsoid hitherto made use of, the *second* auxiliary one. The two ellipsoids are polar surfaces with regard to a concentric sphere whose radius equals unity. The two magnetic axes hitherto defined to be the two perpendiculars to the circular sections of the second auxiliary ellipsoid, may be defined also, with regard to the first auxiliary ellipsoid, to be the axes of the circumscribed circular cylinders. The resulting couple $\frac{2\varphi \sin \xi}{rp}$

may also be written thus,

$$2\varphi p_0 r_0 \sin\xi = \varphi r_0^3 \sin 2\xi,$$

r_0 being the radius vector OM_0 of the first auxiliary ellipsoid lying along $p(=OP)$, and $p_0(=OP_0)$ the perpendicular to the plane touching it in the extremity of this radius vector and coinciding with $r(=OM)$.

47. Let ϱ $(=OE)$ be equal to $r_0 p_0$ and directed along OP and OM_0; let x_0, y_0, z_0 be the coordinates of M_0, and α_0, β_0, γ_0 the angles between $\varrho(=OE)$ and the three axes of coordinates; then

$$\left(\frac{1}{\varrho}\right)^2 = \frac{1}{r_0^3}\left(\frac{x_0^2}{a^4}+\frac{y_0^2}{b^4}+\frac{z_0^2}{c^4}\right) = \frac{\cos^2\alpha_0}{a^4}+\frac{\cos^2\beta_0}{b^4}+\frac{\cos^2\gamma_0}{c^4}.$$

This relation shows that the point E falls on the surface of a new ellipsoid, which may be called the *ellipsoid of induction*. Its three semi-axes are a^2, b^2, c^2. Therefore the ellipsoid of induction and the concentric sphere, whose radius is equal to unity, are two polar surfaces, with regard to the first auxiliary ellipsoid, the polar plane of the point E touching the sphere in a point K, in which the sphere is intersected by OM_0.

By means of the ellipsoid of induction, which may be represented by

$$\frac{x^2}{\alpha^2}+\frac{y^2}{\beta^2}+\frac{z^2}{\gamma^2}=1, \quad \ldots \ldots \ldots \ldots \quad (32.)$$

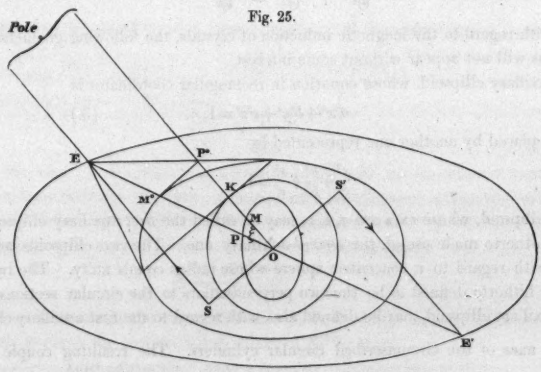
we can completely resolve the proposed question, replacing in all the former formulæ a^2, b^2, c^2 by α, β, γ. Thus, for instance,

$$\cos^2\omega = \frac{\alpha-\beta}{\alpha-\gamma}, \quad \cos 2\omega = \frac{\alpha+\gamma-2\beta}{\alpha-\gamma},$$

whence the two magnetic axes are known.

48. With reference to the relations between the different ellipsoids and the sphere above mentioned, we easily obtain various constructions of POISSON's problem, among which I select the following one (fig. 25).

Fig. 25.



In the general case, where the influenced ellipsoid is free to rotate round its centre, construct the planes touching the sphere in the points K and K′, in which it is intersected by the radius vector OM passing, when prolonged, through the infinitely distant magnetic pole; and let the conjugate poles of these planes, with regard to the first auxiliary ellipsoid, be E and E′. Then EOE′ is a diameter of the ellipsoid of induction; its projection SOS′ on any plane perpendicular to OM (containing, for instance, the centre O) represents the absolute moment of rotation (putting $\varphi=1$), and the line within the same plane, perpendicular to the projection SOS′, is the instantaneous axis of rotation.

49. In order to verify the results emanating from POISSON's theory, I appealed to the known ability of M. FESSEL of Cologne, to turn, out of a homogeneous piece of soft iron, two ellipsoids with unequal axes, the position of the centres and the length of the diameters of one set of their circular sections having been previously calculated. The ratio of the squares of the three axes in both ellipsoids was fixed as follows:—

$$A^2 : B^2 : C^2 = 400 : 160 : 100.$$

According to this ratio, both sets of circular sections were perpendicular to each other, as were also the diameters perpendicular to both sets of circular sections. The longest axis, 2A, of the first ellipsoid was 3·16 inches; the second ellipsoid had only half the dimensions of the first.

50. 1st. The first ellipsoid was attached at the extremities of its longest axis 2A to the inside of a graduated thin ring of brass, the shortest axis 2C coinciding also with a diameter of the ring. The ring was attached to the torsion-balance. We made use of a great horseshoe-electro-magnet placed vertically, and excited by twelve of GROVE's elements. The diameter of the flat poles was about 4 inches, the distance between their centres 10·24. The ellipsoid was brought into such a position that its centre lay in the vertical plane passing through the centres of the two poles, at a distance of 30·74 inches from the point midway between them, nearly 4·1 inches below the horizontal plane touching both poles. A dipping-needle, having its centre similarly placed within the same vertical plane, and by means of a counterpoise pointing horizontally when the current was interrupted, pointed horizontally too when the current was closed.

When suspended with its longest axis 2A vertical, the ellipsoid set its mean axis 2B axially; when with its shortest axis 2C vertical, the same mean axis 2B pointed equatorially. Therefore, as the vertical axis of suspension passes within the principal plane AC, *i. e.* within the middle plane of the ring, from the first position to the second, there ought to be found a position where the mean axis 2B passes from the axial into the equatorial line. Accordingly we got the two magnetic axes of the ellipsoid, equally distant on both sides from the longest axis 2A, and two suspensions corresponding to each axis and correcting each other.

51. In the four suspensions along 25°, 155°, 205°, 335°, the torsion-wire being attached to the ring in the corresponding division, beginning from one extremity of the longest axis and going round from 0° to 360°, the mean axis 2B pointed axially, the longest axis 2A being within the equatorial plane. In the four suspensions along 30°, 150°, 210°, 330°, the mean axis 2B pointed equatorially, the longest axis 2A being within the axial plane; but here the directing power appeared not quite so strong as before, and most weak in the second and fourth of these suspensions. When suspended along $27\frac{1}{2}°$, $152\frac{1}{2}°$, $207\frac{1}{2}°$, $332\frac{1}{2}°$ the ellipsoid set its mean axis 2B axially. Hence the angle, denoted before by ω, is between $27\frac{1}{2}°$ and 30°, about 29°. Therefore the angle between the two sets of circular sections of the auxiliary ellipsoid, *i. e.* the angle between the two magnetic axes, is about 58°, while the two circular sections of the induced ellipsoid of iron are perpendicular to each other.

The same experiment has been repeated exactly in the same way with the smaller ellipsoid of iron. The resulting magnetic axis had nearly the same position as in the former case, the angle ω being fully 30° instead of 29°. This angle was not sensibly changed when the distance from the point midway between the centres of the flat poles of the electro-magnet was increased from 30·74 to 39·37 inches.

52. 2nd. Then we proceeded to a second series of experiments, in order, first, to verify the equation (30.), which may be considered as the test of POISSON's theory; secondly, to determine by means of the method of oscillations the same angle ω which we formerly obtained by direct observation. We made use of the smaller ellipsoid, attached without the divided ring by means of very fine copper wires to the silk thread of the torsion-balance, having its centre always in the same place, 39·37 inches distant from the equatorial plane of the electro-magnet. In three different suspensions the axes 2A, 2B, 2C were successively vertical, the corresponding principal planes, marked by white paint, oscillating horizontally, always at the same height. It had been ascertained that the copper wire did not sensibly increase the moment of inertia of the iron ellipsoid, nor had the torsion of the carefully selected silk thread any sensible influence on the number of oscillations. The current being interrupted, the longer axis of the horizontal section of the ellipsoid was, before oscillating, directed by means of the torsion-balance towards the poles. The observed numbers of oscillations corresponding to different magnetic powers were in full accordance. Here I shall refer only to the last series of observations, where the current was excited by twelve elements, the acids not having been used before, the zinc being newly amalgamated. Immediately after each observation we repeated the experiment, with this difference, that that extremity of the vertical axis which had pointed downwards was now directed upwards. Thus we got two numbers relating to each of the three cases. After having determined the second number of the first case, the ellipsoid was brought again into the primitive position: thus was obtained a third number equal to the first.

TABLE.

Number of oscillations.	Number of seconds required.
	Axis 2B vertical.
18	$\left\{\begin{matrix}169\\170\\169\end{matrix}\right\}$ Mean 169·33
	Axis 2C vertical.
14	$\left\{\begin{matrix}159\\162\end{matrix}\right\}$ Mean 160·5
	Axis 2A vertical.
12	$\left\{\begin{matrix}161\\157\end{matrix}\right\}$ Mean 159.

To control the constancy of the current during the observations, in each suspension the number of seconds corresponding to the first and last half number of oscillations was separately marked; but the number of seconds having been found in all cases equal to half the total number, I thought it not necessary to note it here. Finally, the first observation was twice repeated; we found 166·5 instead of 169·5, indicating a small increase of the magnetic power.

The ratio of the three mean numbers of the Table being independent of the intensity of the current, the next day we determined by observation in a more peculiar way the ratio of the first and second number, and afterwards the ratio of the first and third. In both cases we got small differences. Accordingly, the observation of the first case admitting the greatest accuracy, we retained the first mean number 169·33; instead of the second, 160·5, we adopted 159·75; instead of the third, 159, we adopted 160·2.

The square of the time of one oscillation concluded from the corrected Table is in the three cases

$$\Theta_{n}^{2}=\ 88{\cdot}51,$$
$$\Theta_{m}^{2}=130{\cdot}19,$$
$$\Theta_{l}^{2}=178{\cdot}22.$$

Putting

$$A^2=400,\quad B^2=160,\quad C^2=100,$$

we get

$$A^2+C^2=500,\quad A^2+B^2=560,\quad B^2+C^2=260;$$

therefore

$$\frac{A^2+C^2}{\Theta_{n}^{2}}=5{\cdot}649,$$
$$\frac{A^2+B^2}{\Theta_{m}^{2}}=4{\cdot}301,$$
$$\frac{B^2+C^2}{\Theta_{l}^{2}}=1{\cdot}459.$$

The sum of the last two numbers, equal to

$$5{\cdot}760,$$

differs from the first by only

$$0{\cdot}111,$$

i. e. $\frac{1}{10}$ nearly. This error falls within the limits of the errors of observation.

The equation (30.) being thus verified, we obtain, according to (28.),

$$\tan\omega=\sqrt{\frac{1459}{4301}},$$

whence

$$\omega=30^\circ\ 13'.$$

This value of the angle ω agrees very well with the value concluded, in a less exact way, from the first series of observations *.

III. *Theory of the magnetic induction of crystals, and its experimental verification.*

53. The results we obtained in the preceding section remain unchanged as long as the dimensions of the influenced body may be neglected, with regard to the distance of the pole, *i. e.* as long as within the influenced body the lines of magnetic force are sensibly parallel. The formulæ therefore we deduced from POISSON's theory, relating to a finite ellipsoid influenced by an infinitely distant pole, may be immediately applied to the infinitely small particle of a crystal at a finite distance from the inducing pole. If the particle be placed between two opposite poles, we may substitute for the two poles a single one of double intensity.

54. Let us then conceive, as we did before, the crystal to consist of an infinite number of influenced small ellipsoids, not sensibly acting on each other. Every such ellipsoid will furnish a moment of rotation represented by

$$\frac{2\tan\xi d\phi}{r^2},$$

ξ and r being determined by the auxiliary ellipsoid. The resulting moment of rotation will be represented by the integral

$$2\int\frac{\tan\xi d\phi}{r^2},$$

extended to the entire mass of the crystal. If we admit that all particles of a crystallized mass *are of the same form and similarly directed*, ξ and r become constant, whence the resulting moment,

$$\frac{2\phi\sin\xi}{r^2}.$$

* We may regard here the above-described experiments as a sufficient verification of the results emanating from POISSON's theory, in the case of an ellipsoid of iron influenced by a distant pole. A more complete verification of this theory lies beyond the limits of this paper. The ellipsoid of iron may be replaced by a similar one of cobalt or nickel; according to theory, the angle (2ω) between the two axes will be found to be a different one. We may derive from experiment the value of POISSON's constant k (art. 24, note), and compare the value of the magnetic induction with gravitation. Whatever may be the interest connected with these questions, they must be reserved to another series of experiments; the more so, as our horseshoe-electro-magnet—whose two poles induce a distant ellipsoid in opposite sense, along directions which are to be previously determined by observation—is, for such researches, to be replaced by a system of two cylindric electro-magnets having a common axis.

The moment therefore is the same, as if the crystal, whatever may be its exterior form, were transformed into an amorphous ellipsoid of the same mass.

55. A finite amorphous ellipsoid, attached to any vertical axis, when influenced by an infinitely distant pole falling within the horizontal plane, will be directed in the same way as a similar ellipsoid rotating round its vertical diameter. Having therefore a series of such ellipsoids attached one to another and rotating round a common axis, each of them will be forced into the same position of equilibrium as when rotating alone. Hence a crystal too, oscillating between the two poles, is *directed*, whatever may be its shape, like one of its ultimate particles, *i. e.* like the above-mentioned ellipsoid.

56. Therefore, in the case of the magnetic induction of crystals, the same analytical formulæ subsist, which, in the preceding section, we derived in the case of an influenced amorphous ellipsoid by means of auxiliary ellipsoids. All former formulæ concerning the direction of the crystal remain unchanged. With regard to the formulæ bearing upon the law of its oscillations, we shall suppose the oscillating crystal to be always of a spherical form; then the moment of inertia, corresponding to any vertical axis, is equal to $\frac{2}{5}MR^2$, denoting the mass of the crystal by M and its radius by R. Accordingly, the formulæ (26.), (28.), (29.), (30.) are to be replaced by

$$\Theta^2=\frac{MR^2\pi^2}{5\phi(a'^2-b'^2)}=\frac{MR^2\pi^2}{5\phi(a^2-c^2)}\cdot\frac{1}{\sin\psi\sin\psi'}\quad\ldots\ldots\ldots\quad(33.)$$

$$\frac{\Theta_{II}}{\Theta_I}=\sin\omega,\qquad\frac{\Theta_{II}}{\Theta_{III}}=\cos\omega,\qquad\frac{\Theta_{III}}{\Theta_I}=\tan\omega.\quad\ldots\ldots\quad(34.)$$

$$\Theta^2=\Theta_{II}^2\sin\psi\sin\psi'.\quad\ldots\ldots\ldots\ldots\ldots\quad(35.)$$

$$\frac{1}{\Theta_I^2}+\frac{1}{\Theta_{III}^2}=\frac{1}{\Theta_{II}^2}.\quad\ldots\ldots\ldots\ldots\ldots\quad(36.)$$

In all these formulæ, we suppose known, as we did before, the direction of the three axes $2a$, $2b$, $2c$ of the first ellipsoid, *i. e.* the direction of the axes of greatest, mean, and least induction. The angle between the two magnetic axes is always denoted by 2ω. The time of one oscillation is denoted by Θ_I, Θ_{II}, Θ_{III}, and Θ_I in the cases where the crystal, of a spherical form, successively oscillates round its axes of greatest, mean, and least induction, and round any diameter determined by the two angles ψ and ψ' between it and the two magnetic axes.

57. The first question we here meet with, is to determine for any crystalline substance the constants, especially ω, upon which depends the position of the crystal, when suspended between the poles, and the law of its oscillations.

1st. We may, as shown in the case of ferridcyanide of potassium, sulphate of zinc, and formiate of copper, find by experiment, within the crystal, the two magnetic axes, remembering that the crystal, when suspended along one of them, is not acted upon in an extraordinary way, not at all acted upon when its form is, for instance, that of a sphere.

2nd. Any one suspension of the crystal along a vertical axis, fixed with regard to the axes of induction, is sufficient to determine the angle ω, and hence the position of the two magnetic axes. We may for this purpose make use of the formula (9.), and any

one of the formulæ (11.)–(13.), or of the formulæ (18.), (19.). Reciprocally, ω being determined, we may calculate the position of the crystal in any given suspension, by means of (9.) and (11)–(13.), or of (14.) and (15.).

3rd. Let the spherical crystal be successively suspended along any two diameters, previously determined within it with regard to its axis of induction, and let us take in both cases the number of oscillations it performs in a given time, when brought a little out of its position of stable equilibrium. From the two numbers thus obtained we can easily calculate the value of ω (34.), most easily when the crystal was suspended along any two of its axes of induction (33.).

58. By determining for any crystal the value of the angle ω in the three different ways, we are enabled to verify the theory we have put forward. Such a verification, however, is immediately supplied by the equation (36.), which may be expressed thus:—

The sum of the squares of the numbers of oscillations which a sphere turned out of a crystalline substance performs in a given time, when successively suspended along the greatest and least axis of induction, equals the square of the number of oscillations performed when suspended along the mean axis of induction.

59. Among the crystals I was able to provide, the most proper to be used in order to verify the proposed theory of the magnetic induction of crystals was formiate of copper, which I crystallized myself. After some trials, I succeeded in getting turned, by M. Fessel, out of a fine crystal of this salt, a perfectly homogeneous sphere 0·39 of an inch in diameter. A great circle traced on its varnished surface marked the cleavage plane of the crystal. [In order to verify, after experiment, the position of this plane, the sphere was cloven by means of the heat produced in the focus of a burning lens.] The sphere was supported by a small circular ring of very thin mica, attached by three thin silk threads to the double cocoon-fibre of the torsion-balance. The distance of the pointed poles, the extremities of large iron pieces put on the flat poles of the large electro-magnet, from each other, was about 1·58 of an inch.

60. The sphere was first placed on the ring, with its cleavage plane horizontal, in order to determine the symmetrical plane, this plane being in our case vertical and forced by the power of the magnetic poles into the axial position. After having traced on the surface of the sphere the symmetrical plane thus obtained, we placed it on the ring, with this plane horizontal. The two points, marked on the new great circle, pointing axially and equatorially, indicated the direction of the greatest and least axis of magnetic induction, the mean axis being perpendicular to the symmetrical plane. The two principal planes perpendicular to the symmetrical plane were likewise marked on the surface of the sphere by great circles, one of which, passing through the least and mean axis, is nearly coincident with the cleavage plane, the angle between the two planes being nearly 3°.

61. 1st. We tried first to determine directly the position of the two magnetic axes within the symmetrical plane, by turning the sphere, when influenced by the poles, around the mean axis, the symmetrical plane remaining always vertical. But here we observed that the passage from the axial position of the symmetrical plane to the equa-

torial one takes place gradually, the crystal passing through all intermediate positions while it rotates through several degrees round the mean axis of rotation. This mode of determining ω admits therefore of no great accuracy.

The inclination of the cleavage plane to the horizontal plane was determined, when the symmetrical plane pointed 45°, bisecting the angle between the axial and the equatorial plane. We got for this angle, by inclining the cleavage plane on both sides, on one side 21°, on the other 26°, whence $\omega = 23\frac{1}{2}°$, and the angle between the normal to the cleavage plane and the mean axis $2\frac{1}{2}°$. [Instead of $23\frac{1}{2}°$, we got formerly 25° (art. 21); instead of $2\frac{1}{2}°$, by direct measure 3°.]

62. 2nd. Then the number of small oscillations was counted which the same sphere performed in one second, when successively suspended along its three axes of induction. In one series of observations six, in another twelve of GROVE's elements were used. In both series the crystal was twice suspended along each axis. The following Table furnishes the numbers thus obtained:—

Suspended along	Numbers of oscillations.		
Six elements.			
The greatest axis	$22\frac{1}{2}$	23	$\frac{1}{\Theta_{i}}$
The mean axis	53	53	$\frac{1}{\Theta_{ii}}$
The least axis	49	49	$\frac{1}{\Theta_{iii}}$
Twelve elements.			
The greatest axis	31	$31\frac{1}{2}$	$\frac{1}{\Theta}$
The mean axis	73	73	$\frac{1}{\Theta_{ii}}$
The least axis	67	67	$\frac{1}{\Theta_{iii}}$

From the first series of observations we get

$$\frac{1}{\Theta_{i}^{2}}+\frac{1}{\Theta_{iii}^{2}}=2918, \qquad \frac{1}{\Theta_{ii}^{2}}=2809;$$

from the second,

$$\frac{1}{\Theta_{i}^{2}}+\frac{1}{\Theta_{iii}^{2}}=5166, \qquad \frac{1}{\Theta_{ii}^{2}}=5329.$$

The differences between the two numbers thus obtained in both cases (109 and −163), are so small, with regard to the limits of error, that the theorem of article 58 can be considered confirmed by experiment.

In order to eliminate these small differences, let us remember that the ratio of any two corresponding numbers in the two series of observations is to be the same, this ratio equaling the ratio of the inducing powers of the magnet. Again, in the two series of observations, the numbers corresponding to the same mode of suspension are likewise in the same ratio. These two conditions are fulfilled with regard to the suspensions along

the greatest and mean axis. We get as near as possible

$$\frac{73}{53}=\frac{31}{22\cdot5}=1\cdot38,$$

this number indicating the relative inducing power. We may regard, therefore, the four numbers 22·5, 31, 53, 73 as the most exact. Among all possible vertical axes of suspension, the *minimum* number of oscillations corresponds to a suspension along the greatest axis, the *maximum* number to a suspension along the mean axis. Therefore we are authorized to prefer 22·5 and 31 to 23 and 31·5. In conformity with that, we may, according to our theorem, calculate the numbers of oscillations in the third mode of suspension, which admits the greatest errors of observation. The two resulting numbers are 48·0 and 68·3, instead of 49 and 67. Finally, we obtain (34.),

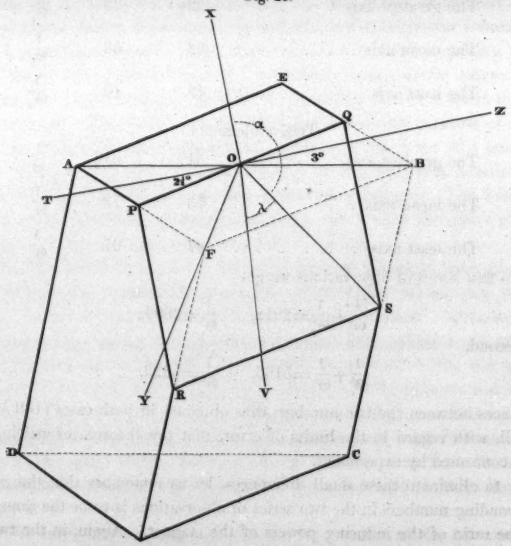
$$\sin\omega=\frac{22\cdot5}{53}=\frac{31}{73},$$

whence

$$\omega=25^\circ\cdot8.$$

63. 3rd. We shall deduce the value of ω from the observed position of an influenced

Fig. 26.



crystal, suspended along any known direction. The crystals I had obtained exhibiting in a very pronounced way several faces of the primitive octahedron, we suspended one of

them with such a face horizontal, and were enabled to observe with accuracy the angle between the equatorial line and an edge of the primitive octahedron, the line of intersection of the horizontal face and the cleavage plane. This angle was found to be $2\frac{1}{2}°$. The same value of the angle was obtained as well by different natural crystals as by a circular plate turned out of a fine crystal, on whose base, lying in the face above mentioned, the direction of the edge was marked by a line, along which, moreover, was attached a long and very thin filament of glass, indicating more distinctly the pointing of the crystal.

Let ABDC (fig. 26) be the symmetrical plane containing the two axes of greatest and least induction OX, OZ; AEBF the cleavage plane perpendicular to the symmetrical plane, and containing the mean axis OY; and lastly, PQSR the horizontally-suspended face of the primitive octahedron, intersecting ABDC in OS and AEBF in the edge PQ. The equatorial and the axial line OT and OV lie in the horizontally-oscillating face PQSR; the measured angle POT equals $2\frac{1}{2}°$. According to M. HEUSSER's measures, the inclination of the face PQSR to the cleavage plane is $51° 31'$, and from his above-quoted angles (art. 17) we derive $QOB=44° 51'$. Hence, considering the rectangular spherical triangle determined by OQ, OS, OB, we get

$$QOS=57° 59', \quad BOS=41° 35\tfrac{1}{2}', \quad \varphi=56° 17',$$

denoting by φ the angle between the face in question and the symmetrical plane. The angle ZOB within the symmetrical plane being 3° (art. 19), we get

$$\alpha=XOS=BOS+93°=134° 35\tfrac{1}{2}',$$

and in like manner

$$\lambda=VOS=POT+90°-QOS=34° 31'.$$

Starting from these values of the angles φ, α and λ, we obtain, by means of the formulæ (9.) and (12.), or (18.) and (19.),

$$\omega=25° 3'*.$$

64. After having expounded the general theory of the magnetic induction of crystals,

* Hitherto we have only determined, by various methods, the value of the angle ω, and thus obtained a linear relation between the three axes of the ellipsoid of induction. If, by considerations exceeding the limits of this paper, we should be enabled to get the ratio itself of these axes, we could hence deduce the form of the magnetic particles of the examined crystal, supposing that, in fact, these particles are similar ellipsoids, similarly directed, all induced by the magnetic pole, but not sensibly inducing each other. Mr. W. THOMSON, however, has published a curious theorem, according to which a body of any exterior shape is influenced by an infinitely distant pole like a certain ellipsoid whose axes are to be determined in each case. Hence an infinite variety of forms corresponds to a known ellipsoid of induction. Again, each physical condition of crystals leading to our ellipsoid of magnetic induction has, to the present time, independently of POISSON's hypothetical views on matter, the same claim to be the law of nature. We may generally conceive an amorphous substance to consist of equal particles, pointing in all different directions, which by the act of crystallization become directed in the same way. But I think it probable we shall obtain the same results by admitting spherical particles, which, according to their different proximity along different directions within the crystal, will equally lead, by their mutual induction, to three axes of induction; thus each such particle may possibly be acted upon in the same way as our ellipsoidal particles.

we may easily apply it to the case where the auxiliary ellipsoids are *ellipsoids of revolution*, and therefore the two magnetic axes coincident along the same line. The crystals in this case are to be called *uniaxal*. We may distinguish too *positive* and *negative* uniaxal crystals. In positive crystals $a^2=b^2$, and therefore $\omega=0$; in negative crystals $b^2=c^2$, and therefore $\omega=90°$. The induction in both cases may be as well a diamagnetic as a paramagnetic one.

65. Since the two axes of the horizontal section of the first auxiliary ellipsoid point axially and equatorially, as they do in the general case, the position of a uniaxal crystal, when suspended between the two poles along any of its diameters, is immediately obtained. Here the axis of revolution, *i. e.* the magnetic axis of the crystal, when projected on the horizontal plane, is one of these two axes, the other being the intersecting line of the equatorial plane of the ellipsoid and the horizontal plane. If the crystal be positive, this intersecting line is coincident with the shorter axis of the elliptical section within the horizontal plane; if it be negative, with the longer axis. Hence a paramagnetic crystal, when positive, sets its magnetic axis in the axial, when negative in the equatorial plane of the electro-magnet. In diamagnetic crystals, when positive, the magnetic axis is forced into the equatorial, when negative into the axial plane. In order to give a true description of this fact, you may say, in all cases the magnetic axis of the crystal is either attracted or repelled by the poles.

This law can easily be verified in a most distinct way by a great number of paramagnetic and diamagnetic, positive and negative crystals. I think it therefore not necessary to refer here to new experiments.

66. In most cases the magnetic axis is known, if not, it can easily be found by suspending the crystal along any two vertical axes. Mark in both suspensions if the crystal be positive and paramagnetic, or negative and diamagnetic, on its surface the axial plane, if it be positive and diamagnetic, or negative and paramagnetic, the equatorial plane; in both cases the line of intersection within the crystal of the two planes marked on its surface is the magnetic axis.

67. The law of the small oscillations of the crystal, which again, for simplicity, we suppose of a spherical form, when suspended between the poles along any vertical axis, is represented by the former equations (33.) and (35.), now simplified thus:

$$\Theta=\frac{MR^2\pi^2}{5\varphi(a^2-c^2)}\cdot\frac{1}{\sin\psi^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (37.)$$

$$\Theta_0=\Theta\sin\psi, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (38.)$$

denoting by Θ the time of one oscillation, if the angle between the magnetic axis and the vertical axis of suspension equal ψ, and Θ_0 the time of one oscillation if $\psi=90°$, *i. e.* if the magnetic axis oscillate horizontally.

68. Remembering a former observation, according to which sulphate of iron, although belonging to the clinorhombic system, ranges among uniaxal crystals, having its magnetic axis within the symmetrical plane, I selected this salt to verify the last formula. I

provided a small but most homogeneous and transparent sphere, on whose varnished surface the symmetrical plane was marked by a great circle.

We succeeded first in establishing the former observation. The sphere of sulphate of iron was suspended between the two poles, as formerly the sphere of formiate of copper was, with this difference only, that, on account of the stronger paramagnetic induction, we made use of only two of GROVE's elements instead of six. The sphere was first placed on the ring with the symmetrical plane horizontal, and the direction within it pointing axially, marked by a point on the corresponding great circle. The sphere being then placed on the ring, with the symmetrical plane vertical and the marked point situated in the vertical axis of suspension, did not move under the influence of the magnetic poles. Hence sulphate of iron is a uniaxal positive and paramagnetic crystal.

The sphere was then put on the ring successively with its symmetrical plane horizontal, and inclined 45° alternately on one side and the other.

The symmetrical plane.	Number of seconds required for twenty oscillations.	
Inclined +45°	60	
Horizontal		44
Inclined −45°	64	
Horizontal		45
Inclined +45°	61	
Horizontal		46
Inclined −45°	$65\frac{1}{2}$	
Horizontal		45
Inclined +45°	$63\frac{1}{2}$	
Mean numbers	$62{\cdot}8=\Theta_0$	$45=\Theta_0$

Hence

$$\frac{\Theta_0}{\Theta}=0{\cdot}715 \quad \sin\psi=\sin 45^\circ=0{\cdot}707\,;$$

therefore, in this case also, the theory is fully confirmed by experiment.

69. Being desirous of examining in like manner a uniaxal and diamagnetic crystal, I selected a beautiful specimen of crystallized bismuth, showing the cleavage in the most perfect way. A sphere, 0·79 of an inch in diameter, was turned out of it, and on its surface was traced the equatorial circle, indicating the cleavage plane, and any meridional circle passing through the magnetic axis. But this sphere, on account of the electric currents excited within it, while it oscillates between the two poles, could not be subjected to experiment in the same way as the sphere of sulphate of iron. This is the case with regard to all substances enjoying a great conducting power, and not being magnetically influenced in so high a degree as iron, cobalt, and nickel.

70. Therefore, in order to verify the theory which has been expounded with regard to our sphere of crystallized bismuth, when suspended along its different diameters, we

were obliged to recur to the formula (24.), expressing the moment of rotation (L) round any vertical axis,

$$L=\phi(a'^2-b'^2)\sin 2\vartheta=\phi(a^2-c^2)\sin^2\psi\sin 2\vartheta. \quad . \quad . \quad . \quad . \quad . \quad (39.)$$

In this formula the angle between the vertical great circle of the sphere passing through the magnetic axis and the axial plane is denoted by ϑ, and the angle taken on the same great circle between the magnetic and the vertical axis by ψ. Denoting the value of the moment corresponding to $\psi=90°$, where the magnetic axis is vertical, by L_0, we obtain

$$L=L_0\sin^2\psi. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (40.)$$

The angle ψ remaining the same, the maximum of L corresponds to $\vartheta=45°$; denoting this maximum by L^0, we get

$$L=L^0\sin 2\vartheta. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (41.)$$

71. The sphere of crystallized bismuth was placed on a ring of very thin, not paramagnetic, copper wire, attached by three silk threads to the platinum wire of the torsion-balance. The centre of the sphere was brought into the middle point between the two poles, its marked meridional great circle remaining always vertical.

When the equatorial great circle was horizontal, there was no sensible direction; the torsion-wire being turned through any angle, the sphere rotated round its vertical axis through the same angle. When the equatorial circle was more and more inclined, the directing power emanating from the poles, *i. e.* the moment L, increased till the equatorial plane became vertical, and therefore the magnetic axis horizontal. Let us consider in a more special way this last case, corresponding to $\psi=90°$, and the case corresponding to $\psi=45°$. In all cases the marked meridional plane points axially: so it did in our two cases most exactly, after it had been brought by means of the torsion-balance into that position while the current was interrupted. The current being established, by turning the platinum wire the meridional circle was brought out of the axial position. If the number of degrees through which the wire rotated be δ, and the declination of the meridional plane of the sphere from the axial position ϑ, the number $\delta-\vartheta$ indicates the value of the moment of rotation in the corresponding position of the crystal. The number of degrees $(\delta-\vartheta)$ corresponding to different values of ψ, but to the same declination ϑ of the meridional plane of the crystal from the axial position, is proportional to $\sin^2\psi$. In our two cases these corresponding numbers are in the ratio of 2 : 1. It was confirmed by experiment.

72. While in the first suspension the torsion-wire was slowly turned, the angle of declination more and more increased; but finally, just when it reached 45°, corresponding to a certain value of δ, the crystalline sphere was suddenly driven into a nearly opposite position of stable equilibrium. A similar reversion took place after a rotation of the wire of the torsion-balance in the same sense through 180° more, and so on. In our second case, we got the same phenomena, with this difference only; that the first reversion took place when the torsion-wire was turned through a smaller number of degrees. In both cases we made use of twelve of GROVE's elements.

In the first case, the value of δ, in the moment when the first reversion took place, in two successive observations was found to be

$$\left.\begin{matrix}561\\563\end{matrix}\right\}\text{Mean } 562\,;$$

in the second case, we obtained

$$\left.\begin{matrix}295\\300\end{matrix}\right\}\text{Mean } 297{\cdot}5\,;$$

whence

$$\frac{297{\cdot}5-45}{562-45}=\frac{252{\cdot}5}{517}=0{\cdot}498,$$

consequently very near the value of $\sin^2\psi=0{\cdot}5$.

·73. The declination (ϑ') of the meridional plane, after the suspension of the crystal, may easily be calculated. Let the number of degrees through which the meridional plane rotates, when passing from the position of unstable equilibrium, corresponding to $\vartheta=45°$, into the new position of stable equilibrium, be denoted by z, whence $\vartheta'=z+45$. Then, according to (41.), we get

$$\sin 2(z-135)=\frac{\delta-45-z}{\delta-45},$$

whence

$$\sin^2 z=\frac{z}{2(\delta-45)}. \qquad (42.)$$

In our first case, where $\delta-45=517$, we obtain

$$z=157{\cdot}05,\quad \vartheta'=180°+22°\ 3';$$

in the second case, where $\delta-45=252{\cdot}5$,

$$z=147{\cdot}30,\quad \vartheta'=180°+12°\ 18'.$$

These values, according to an approximative estimation, agree with observation*.

* The same mode of experimenting may be applied to the general case of biaxal crystals, by substituting for the formula (39.),

$$L=\varphi(a^2-c^2)\sin\psi\sin\psi'\sin 2\vartheta\,;$$

denoting, as we did before, the angles between the vertical and the two magnetic axes by ψ and ψ'. When the vertical axis successively coincides with the axes of greatest, mean, and least induction, the corresponding moments of rotation are

$$L_{i}=\varphi(a^2-c^2)\sin^2\omega\sin 2\vartheta,$$
$$L_{ii}=\varphi(a^2-c^2)\sin 2\vartheta,$$
$$L_{iii}=\varphi(a^2-c^2)\cos^2\omega\sin 2\vartheta\,;$$

whence, corresponding to any value of ϑ,

$$L_{i}:L_{ii}:L_{iii}=\sin^2\omega:1:\cos^2\omega.$$

Hence we may determine by experiment the position of the two magnetic axes of a crystal in the following new way, allowing of great accuracy. Attach the crystal, after having given to it the form of a sphere, to the wire of the torsion-balance, and let there be no torsion when the sphere influenced by the poles takes a certain direction. Let, successively, the axis of greatest, mean, and least induction be vertical, and determine in each suspension the number of degrees through which the torsion-wire, slowly turned, rotates till the reversion of the sphere takes place. *The sum of the numbers thus obtained in the first and the third case equals the number obtained in the second case.* The first number divided by the second equals $\sin^2\omega$; the third by the second, $\cos^2\omega$; the first by the third, $\tan^2\omega$.

IV. *Position of the three axes of magnetic induction with regard to the primitive form, in crystals belonging to different systems.*

74. A great number of crystals, the finest of which were supplied by the extreme liberality of Professor BÖTTGER of Frankfort, have been examined by myself in connexion with Professor BEER, in order to establish their optic as well as magnetic properties, with regard to their crystalline form. The results are published in two papers in POGGENDORFF'S 'Annalen.' A third paper, ready to be sent to press nearly two years ago, did not appear, since, according to the newly-adopted theory, I found it necessary to present the results obtained by experiment in a different way. From these papers are taken nearly all the observations referred to in this section.

75. In crystals having *no* plane of symmetry, there is not the least indication of the position of the three unequal axes of magnetic induction. In no case has the position of these axes been determined.

Sulphate of copper is a crystal of this kind, strongly exhibiting the extraordinary action. I provided a sphere, turned out of a large crystal, in order to determine the position of the three axes of induction, and hence the two magnetic axes. According to art. 39, I intended to trace on its surface the two curves indicating the diameters which point axially and equatorially, when the sphere, suspended between the two poles, rotates successively round any two horizontal diameters. The practicability of this proceeding had been previously proved in the case of crystals belonging to a different system; but here we did not succeed, on account of the want of homogeneity of the sphere of sulphate of copper, which in its different parts contained different quantities of sulphate of iron *.

Cyanite furnishes another instance of extraordinary paramagnetic induction. Strongly paramagnetic prisms of this mineral show the extraordinary action, when suspended horizontally, in a sensible way, *even under the magnetic induction of the earth.* Rotating round their horizontal axis, they point towards different azimuths.

Bichromate of potash shows very distinctly the extraordinary paramagnetic, racemic acid the extraordinary diamagnetic induction.

76. The crystals *having a single plane of symmetry* may be referred to an oblique prism with a rhombic base, the plane of symmetry passing through one of the diagonals of the base. Two axes of paramagnetic induction always lie in the plane of symmetry, the remaining third one being perpendicular to it. When any crystal of this system is to be examined, you may suspend it first along the line perpendicular to the

* All specimens of copper, except of English, which I had the opportunity to examine, were found to be strongly paramagnetic, even such specimens as were obtained by galvano-plastic deposition; so were all salts of its oxides. I was first inclined to attribute the paramagnetic condition in both cases to unmixed iron; but on closer examination, I convinced myself that oxide of copper is paramagnetic *per se*, and so are all its salts; in like manner as copper, dioxide of copper and its salts (sulphite of copper and ammonia, $\dot{C}u\,\dot{S} + Am\,\dot{S}$) are diamagnetic.

symmetrical plane, and mark within this plane the directions both axial and equatorial. These two directions, representing the two axes of induction within the symmetrical plane, are not at all indicated by the crystalline form; they are to be found by experiment. The crystal, when successively suspended along each of the three axes of paramagnetic induction, sets one of these axes twice axially, another one twice equatorially. In the case of paramagnetic induction, the first axis is the longest, the second the shortest. In the case of diamagnetic induction, the second axis, pointing twice equatorially, is the longest, the first the shortest one. In both cases, the two magnetic axes lie in the plane passing through these two axes of induction. Therefore the plane containing the two magnetic axes is either coincident with the symmetrical plane, or is perpendicular to it. We may distinguish three different cases, whether the crystal be paramagnetic or diamagnetic: 1. the axis of greatest, 2. the axis of least, 3. the axis of mean magnetic induction is perpendicular to the plane of symmetry. In the first two cases, the plane containing the two magnetic axes is perpendicular to the symmetrical plane, in the third case it falls within it.

	Paramagnetic crystals.	Diamagnetic crystals.
First case . .	Diopside.	Hyposulphite of soda ($\dot{N}a\ddot{S}$).
	Red ferridcyanide of potassium.	
Second case. .	. . . . .	Acetate of soda.
	. . . . .	Acetate of lead.
Third case . .	Formiate of copper.	
	Acetate of copper.	

77. The crystals whose primitive form can be referred to a right prism with a rhombic base have *three planes of symmetry*, intersecting each other along the three axes of magnetic induction. We can, as we did in the former case, determine, by suspending the crystal successively along each of these axes, which of them is the longest, mean, and shortest. The two magnetic axes, always to be sought within the plane of the longest and the shortest axis of induction, lie in any one of the three planes of symmetry. We may distinguish six different cases, as well of paramagnetic as diamagnetic induction.

We shall denote, as we did in the first section, the axis of the right prism, the shorter and the longer diagonal of its base, by α, $\varkappa$, λ, the longest axis of the ellipsoid of induction (art. 47.) being always a^2, the mean b^2, and the shortest c^2. The six cases above mentioned may then be enumerated thus:—

	a^2	b^2	c^2		
falling within					
1.	$\varkappa$	α	λ	paramagnetic,	Sulphate of nickel.
				. . . . . ,	Sulphate of nickel and zinc.
				diamagnetic,	SEIGNETTE'S salt.
2.	λ	α	$\varkappa$		

3.	α	$\varkappa$	λ	diamagnetic,	Aragonite.
				. . . . . ,	Sulphate of zinc.
4.	λ	$\varkappa$	α	paramagnetic,	Staurolite.
				. . . . . ,	Ferridcyanide of lead ($3PbCy+FeCy^3$).
				. . . . . ,	Sulphate of zinc and iron.
				. . . . . ,	Sulphate of magnesia and iron.
				diamagnetic,	Anhydrite.
				. . . . . ,	Hyposulphate of soda (NaS).
5.	α	λ	$\varkappa$		
6.	$\varkappa$	λ	α	paramagnetic,	Ferridcyanide of potassium.
				diamagnetic,	Sulphur.
				. . . . . ,	Citric acid.

In the cases 1 and 2, the two magnetic axes lie in the base of the right prism; in the cases 3 and 4, in the plane passing through its axis and the longer diagonal of its base; in the cases 5 and 6, in the plane passing through its axis and the shorter diagonal of its base.

In all cases, either the acute or the obtuse angle between the two magnetic axes is bisected by the axis of greatest magnetic induction. We shall count the angle 2ω from 0° to 180°, this angle being always bisected by the axis of greatest induction. [If this angle be counted up to 90° only, we may, analogously as in optics, according as the acute angle between the magnetic axes is bisected by the axis of greatest or by the axis of least induction, call the crystals magnetically positive or negative.]

78. In crystals having *one straight line of symmetry*—primitive form: rhombohedron, prism with a hexagonal base, prism with a square base—the ellipsoid of induction becomes a spheroid whose axis of revolution coincides with the line of symmetry. This line is likewise the magnetic axis. We meet in each of the two cases of magnetic induction with two classes of crystals. Here the crystals of the first class shall be called *positive*, of the second class, *negative*. In positive crystals the line of symmetry coincides with the axis of greatest paramagnetic or diamagnetic induction, in negative crystals with the axis of least induction. A uniaxal crystal, when suspended along any vertical axis, sets, if paramagnetic and positive or diamagnetic and negative, its magnetic axis in the axial; if paramagnetic and negative or diamagnetic and positive, in the equatorial plane.

Paramagnetic crystals.

Positive ($a^2=b^2$).	Negative ($b^2=c^2$).
Carbonate of iron.	Tourmaline.
Scapolite.	Beryl.
Green uranite.	Dioptase.
Sulphate of copper and calcium.	Vesuvian.
Sulphate of magnesia (containing iron).	Sulphate of nickel.
	Chloride of ammonium and copper ($AmCl+CuCl+2\,aq$).

Diamagnetic crystals.

Positive ($a^2=b^2$).	Negative ($b^2=c^2$).
Calcareous spar.	Bismuth.
Antimony.	Arsenic.
Molybdate of lead.	Ice.
Arseniate of lead.	Zircon.
Sulphate of potash.	Honeystone.
Nitrate of soda.	Cyanide of mercury.
	Arseniate of ammonia.

79. In all crystals belonging to the *tesseral* system, the ellipsoid of magnetic induction is reduced to a sphere, its three axes being equal to each other. There is *no* extraordinary action.

80. In different biaxal crystals the angle (2ω) between the two magnetic axes passes through all degrees from 0° to 180°. It is about 90° in sulphate of zinc. It is small in staurolite, near 180° in SEIGNETTE's salt. In both cases the two magnetic axes approach to the longer diagonal of the base of the primitive right prism; in the first case the difference between the greatest and mean, in the second case the difference between the mean and least axis of induction is small. Along the longer diagonal the paramagnetic induction of staurolite is greatest, the diamagnetic induction of SEIGNETTE's salt least. The plane containing the two axes has been determined by observation; it passes in the first case through the axis of the prism, in the second case it coincides with its base.

But if, in the case of three unequal axes of induction, the difference between any two of these axes becomes too small, the crystal, when examined between the poles, will exhibit the appearances of a crystal with only one magnetic axis. Crystals of this kind are the following ones:—Sulphate of iron, succinic acid, borax, cyanide of nickel and potassium.

Sulphate of iron, showing very strongly the extraordinary paramagnetic induction, may be regarded as a positive uniaxal crystal; its magnetic axis coincides with FRESNEL's axis of greatest elasticity, being, within the plane of symmetry, inclined 75° to the cleavage plane.

Succinic acid, showing strongly the extraordinary diamagnetic induction, may be regarded as a positive uniaxal crystal, whose magnetic axis coincides likewise with FRESNEL's axis of greatest elasticity.

Borax may be regarded as a diamagnetic negative crystal; its magnetic axis, coinciding with FRESNEL's axis of least elasticity, is perpendicular to the plane of symmetry (the cleavage plane).

Cyanide of nickel and potassium also ranges among diamagnetic negative crystals; its magnetic axis coincides with FRESNEL's axis of least elasticity, and accordingly lies in the plane of symmetry.

81. A crystal not belonging to the tesseral system will nevertheless show no extraordinary magnetic action, if all its three axes of induction are nearly equal to one

another. This is the case in the following crystals:—Oxide of iron (Eisenglanz), yellow ferrocyanide of potassium, cyanide of copper and potassium, quartz, sulphate of potash (whose primitive form is a rhombic prism), and topaz.

Note added during the printing of the paper.

The analogy between the phenomena presented by crystals in the case of light transmitted through them, and in the case of magnetic induction, may be fully explained by the circumstance that in both cases the laws of these phenomena depend upon an auxiliary ellipsoid. The diameters of the *optic* auxiliary ellipsoid represent the values of the reciprocal of the elasticity of the ether within the crystal; two of its axes coincide with the directions of the greatest and the least elasticity, the third and mean axis being perpendicular to these. On the other hand, the axes of the *magnetic* auxiliary ellipsoid are directed along the lines of the greatest, the least, and the mean magnetic induction, and their lengths represent the values of the reciprocal of these three inductions. This analogy becomes the more perspicuous and striking by the fact, that in the first case the *optic axes*, i. e. the two directions along which there is no double refraction, are perpendicular to the circular sections of the optic auxiliary ellipsoid; while in the second case, the *magnetic axes*, i. e. two lines such that the crystal on being suspended along either of them, between the two magnetic poles, is not acted upon by these poles in any extraordinary way, are perpendicular to the circular sections of the magnetic auxiliary ellipsoid.

In crystals with only one principal crystallographic axis, both auxiliary ellipsoids, the optic and the magnetic, become ellipsoids of revolution whose principal axis coincides with the crystallographic axis. In crystals whose primitive form is a right prism with a rhombic base, the three axes of both auxiliary ellipsoids are directed along the three principal crystallographic axes, but in both cases there is no indication at all given about the relative length of the three axes. In crystals belonging to the monoclinic system there is only one axis common to both auxiliary ellipsoids, this axis being perpendicular to the symmetric plane; the two remaining axes of both ellipsoids lie in this plane, where their position, not indicated by any general law, may be easily found by observation. In triclinic crystals there is no indication whatever given by the crystallographic form, regarding the position of the axes of the two ellipsoids, and therefore the determination of these axes is more difficult.

When a plane luminous wave is transmitted through a crystal along any direction, the vibrations in the front of the wave take place along the two axes of the ellipse, in which the optic auxiliary ellipsoid is intersected by the front. Experimentally these directions are determined by putting a plate of the crystal, bounded by faces parallel to the front of the wave, on a polarizing apparatus, and by turning it till it appears dark. Then one of the two directions of vibration lies in the primitive plane of polarization,

the second is perpendicular to it. On the other hand, when a crystal is perpendicularly suspended between the two magnetic poles along any diameter of the magnetic auxiliary ellipsoid, one of the two axes of the horizontal elliptical section of this ellipsoid will point axially, the other equatorially. FRESNEL showed already that, by a simple geometrical construction, the two directions of vibration of any plane luminous wave may be deduced from the position of the two optic axes. I showed in the preceding paper and proved it by observation, that exactly the same construction gives the position of a crystal freely oscillating between the two poles of a magnet; the two horizontal lines pointing axially and equatorially are immediately obtained by projecting the two magnetic axes on the horizontal plane, and by bisecting the angle between these projections. In treating the inverse problem, "to find the magnetic axes of a crystal after having determined by observation the position which the crystal takes between the two poles, when suspended along any known direction," I proposed trigonometrical formulæ, which may be generalized in the following manner. Suppose OX, OY, OZ to be the three principal axes of induction, without knowing their relative values; let, within the suspended crystal, MON be the horizontal plane passing through the centre O and intersecting the principal plane OZ along OM; let ON be, within the horizontal plane, the line pointing either axially or equatorially. Denote by φ the angle between the planes MON and XOZ, by α and λ the angles MOX and NOM. Thus the position, within the crystal, of the horizontal plane is determined by the angles φ and α, the position of the crystal by the angle λ. After having determined, by means of the following two equations,

$$\tan(\eta+\alpha)=-\frac{\tan\lambda}{\cos\varphi},$$

$$\tan(\eta'+\alpha)=\frac{\cos\lambda}{\cos\varphi},$$

the two auxiliary angles η and η', calculate the value of the expression $\tan\eta\tan\eta'$. This value may be found to be either positive or negative; if negative, the absolute value may be either <1 or >1. Thus we obtain *three* different cases.

The position of the two magnetic axes is fixed by knowing the principal plane containing both axes, and the angle between each of them and a given one of the two axes of magnetic induction lying in the same plane. Denoting this angle by ω, we have, in the *first* case,

$$\tan\eta\tan\eta'=\tan^2\omega.$$

Both axes lie in the plane XOZ, ω being the angle between each of them and the axis OX. The last formula holds in both cases; the axis OX may be the axis of the greatest or of the least induction. From this axis the angle ω is to be measured.

In the *second* of the three above-mentioned cases, we obtain

$$\tan\eta\tan\eta'=-\sin^2\omega.$$

The two magnetic axes lie in the plane XOY, perpendicular to the plane XOZ, and

intersecting this plane along OX, which may be the axis of greatest or least induction. The angle ω is to be measured from OX.

In the *third* case we have

$$\tan\eta \tan\eta' = -\frac{1}{\sin^2\omega}.$$

The two axes are situated in the plane ZOY perpendicular to the plane XOZ, and intersecting this plane along OZ, which may be the axis of the greatest or least induction. The angle ω is to be measured from OZ.

In the preceding paper I gave only the formulæ of the first case, where I supposed OX to be the axis of greatest induction. From this formula the others are easily deduced.

The magnetic axes of a crystal, either paramagnetic or diamagnetic, not examined before, whose primitive form is a right prism with a rhombic base, may, for instance, immediately be found by means of these formulæ. In this case, let the axes OX, OY and OZ coincide with the crystallographic axes in any order whatever; cut by parallel planes, whose inclination to these axes is known, a plate out of the crystal; let this plate oscillate horizontally between the two poles of the magnet, and mark on its surface a line pointing either axially or equatorially. Thus the angles φ, α and λ being determined, η and η', as well as $\tan\eta' \tan\eta'$, can be easily calculated. The sign and the value of the last expression shows by which of the last three equations the angle ω is to be calculated, and immediately indicates in which of the three principal planes the two magnetic axes are situated.

The position of the optic axes may be found *by the very same formulæ*. If we make use of the former plate, the angles φ and α remain the same, the angle λ only varies, and is to be determined by means of a convenient polarizing apparatus.

The optic axes relative to different colours being dispersed in the same principal plane, and even passing in certain cases from one principal plane to another, we cannot be surprised that the optic and magnetic axes are differently directed, and placed either in the same or in different planes. In ferridcyanide of potassium, for instance, the axis of the right prism is the axis of the greatest optic elasticity and of the least magnetic induction; the longer diagonal of the base is the axis of the least elasticity and mean induction; the shorter diagonal the axis of the mean elasticity and greatest induction. Therefore the two principal planes, containing the optic and the magnetic axes, intersect each other along the axis of the prism. In the case of sulphate of zinc, the axis of the prism is the axis of the mean optic elasticity and of the greatest diamagnetic induction; the longer diagonal of the rhombic base is the axis of the least elasticity as well as of the least induction; the shorter diagonal is the axis of the greatest elasticity and the mean induction. Accordingly the two optic axes lie in the base of the prism, the two magnetic axes in the plane passing through the axis of the prism and the longer diagonal of its base. In the case of formiate of copper, the mean axis of paramagnetic induction and that of optic elasticity are both perpendicular to the symmetric plane of the crystal; therefore the two optic axes and the two magnetic ones lie in this plane.

By turning, within their plane, each of the two optic axes for violet light in the same direction, these axes will pass into the position of the axes for red light, and afterwards, by turning still in the same direction, into the position of the magnetic axes. In common with Professor BEER, I examined a great number of crystals, in order to find a general law between the position of the magnetic axes of a crystal and its optic axes for the different colours, but without a satisfactory result. The laws mentioned in the second paragraph of these additional pages, by means of which we can in the simpler cases deduce from the primitive form of a crystal the position of the axes of both auxiliary ellipsoids, the magnetic and the optic—and also of all such auxiliary ellipsoids regarding, for instance, molecular elasticity, conduction of heat and electricity—are all we know.

I added this note to my original paper, in order to explain more distinctly than I did before the analogy between the optic and magnetic axes, which guided me during the different stages of my researches on the magnetic induction of crystals. My intention was not at all to enter into the mathematical solution of the great physical problem. All my experimental researches follow from the mere fact, that there exists an auxiliary ellipsoid of magnetic induction. The supposition of molecular ellipsoids of isotropic, paramagnetic or diamagnetic matter, is to be regarded as a means of discovering the mathematical laws to which the couple, tending to turn round a magnecrystal in a uniform field, was subject, and not as establishing these laws on a basis of molecular physics. Such a basis is to be obtained by Professor W. THOMSON's theory only, which I highly regret not to have known when I wrote my paper. From this theory too, an abstract of which appeared in the Philosophical Magazine (March 1851), the above-mentioned auxiliary ellipsoid follows. Theoretically speaking, it was wrong to replace it by POISSON's auxiliary ellipsoid, but this mistake does not in the least way affect the object of the paper presented to the Royal Society.

XXVIII. *On the Development of Decapod Crustacea.* By C. Spence Bate, *F.L.S., &c.* *Communicated by Sir* W. Snow Harris, *F.R.S.*

Received May 1,—Read June 18, 1857.

Many years have elapsed since Mr. Vaughan Thomson made the important discovery that the *Zoëa* of naturalists was but the immature form of an adult Decapod.

His fortunate observation was received with the greatest caution by zoologists in general, and several undertook researches upon the subject to demonstrate the error into which they assumed he had fallen. The researches of Rathke upon the *Astacus fluviatilis*, of MM. Milne-Edwards and Audouin upon marine Decapoda, together with those of Mr. Westwood upon the genus *Gegarcinus*, for a considerable period delayed the general acceptation of the fact that the *Zoëa* is the larva of a Decapod.

Rathke, in 1840*, published the results of a second investigation on the subject, being his researches upon *Pagurus*, *Astacus marinus*, and *Hyas*. In these he corroborated the statements of Mr. Thomson, and admitted that, "relying on the history of the development of the Crayfish, and trusting too much to analogies in the structure of full-grown Decapods," he had done Mr. Thomson injustice in not putting faith in his discovery.

It was not long after Mr. Thomson's first valuable discovery that good fortune placed within his reach the opportunity to show some other changes that the young animal passed through in its transition to a perfect creature; and by a singular coincidence, the same volume of the Philosophical Transactions which contains Mr. Westwood's refutation of what he calls Mr. Thomson's theory, also contains that latter gentleman's further discoveries of what has been termed the metamorphoses through which the animal passed in its growth to the mature Crab; and where he demonstrates that the *Zoëa* and *Megalopa* of naturalists are but two forms in the development of one and the same animal. Mr. Couch, Mr. Goodsir, M. Joly, Captain Du Cane, Rathke, Bell, and most naturalists have since confirmed the assertion of Mr. Thomson, and affirm that two remarkable metamorphoses take place during the progressive development to the adult stage. This is accepted as the present state of our knowledge in Dr. Carpenter's recent work on the microscope, and in Professor Bell's 'British Crustacea.'

To this general rule a few exceptions exist. The Land-crabs and freshwater Crayfish form the most important. Beyond these we know of none in the same orders of Crustacea, the young of which quits the ovum with all its members developed and closely approximating in form to that of the adult.

* Annals of Natural History, vol. vi.

This is the case with all the Edriophthalma; and in the Report upon the British Species which I was requested to lay before the Members of the British Association, the following passage occurs:—"In the highest types of Crustacea, the immense variety of change from the *Zoëa* to the adult animal is but the result of *subordinate* becoming *more important* parts, together with the development of others not yet present, and therefore hardly acceptable under the signification of metamorphosis*."

It is this opinion that I am now, to the best of my ability, about to demonstrate, that from the *Zoëa* or larval form to that of the well-developed Decapod, there is no sudden change such as is understood by the term metamorphosis, and generally believed by naturalists; but that the development is gradually progressive throughout; that some parts are absent, and that some which are present may become obsolete, but that each part undergoes gradual transformation.

In order to arrive at a degree of certainty, the researches upon this subject have been confined to one species, others being used as collateral evidence only. The larvæ in the earliest stages were procured direct from *Carcinus Mænas*, being hatched in my own possession. Those of a later period have been the result of two or three years' accumulations, most of which were taken in Plymouth Sound. Thus procuring a number, I have been enabled to trace through a scarcely broken chain the progressive development of the respective parts up to that which they assume in the adult animal.

The embryo, when it first quits the egg (Plate XL. fig. A), is enclosed within a general tunic, which embraces each individual member and is conformable to the whole animal. This tunic is of extreme tenuity and exceedingly transparent; it is very liable to be overlooked without close observation. Within this tunic may be distinctly seen the hairs belonging to each part respectively. These are not extended, but retracted with telescopic joints, within the members of which they form appendages. In this way also the larger processes of the caudal extremity (fig. 21′) are contracted within shorter limits, as are also the horn-like processes upon the dorsal surface and frontal region. These two are moreover folded down, the dorsal laid forward upon the top of the head, the frontal brought down between the eyes and compressed beneath the frontal region (fig. A). In this embryonic condition the animal swims about for a few hours. It then liberates itself from the general tunic by throwing off that portion which covered the head and *pereion*, anteriorly, while that which protects the *pleon* is drawn off posteriorly†.

The animal is now freed from its embryonic condition, and more actively sports in the water, and procures its own food. Its gambols are produced, partly by the action

* The author is perfectly aware that in Insecta the change of the animal within the chrysalis is gradual in development; but he wishes to show that there is no stage in Crustacea answering to the chrysalis; that the moults in process of development of the Crustacea are of the same kind as those which take place in the adult condition.

† The terms used in this paper are those suggested by the author in his Report on the British Edriophthalma (British Association Report for 1855, p. 27), instead of the old and incorrect synonyms of Thorax, Abdomen, &c. The accompanying diagram of an imaginary *Zoëa* exhibits the details in position.

The term *pereion* is derived from περαιόω, *to walk about*, being that portion of the animal which supports

of the entire *pleon*, and partly by the gnathopoda, the (so-called) natatory feet. They together induce a jerking motion in a progressively circuitous course.

In this stage I have carefully and extensively examined every part of the animal both in position and in detail.

The *carapax* covers almost the whole of the *pereion*, and extends in front to a long projecting rostrum, which is nearly half the length of the entire animal. A similar projection arises from the centre of the dorsal region, and gives an increased eccentricity to its general appearance—a circumstance which has lent considerable force to the belief of an exaggerated metamorphosis in the history of the development of the Crab.

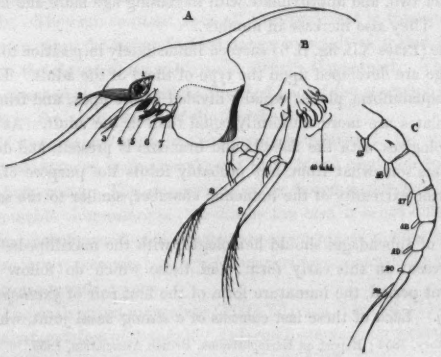
In this early stage the dorsal spine is no mere ornament, but possesses a specific use in supporting the heart in its position. We thus are enabled to identify its exact position in the homologies of the adult, with the cardiac region on the carapax, which in some genera are actually represented by a stout spinous protuberance. It appears moreover to be analogous in purpose to the two strong processes found upon the internal surface of the same region of the carapax in *Carcinus* and other genera.

Posteriorly, as in the adult animal, the carapax is centrally attached to the *pleon* by a membrane, while on each side it is free, so as to admit even at this early period an inpouring current of water to aërate the branchiæ. Laterally the carapax overhangs the *pereion* and protects the coxæ of the developed members, but anteriorly it is compressed so as to leave the eyes prominent.

In the early form the eye is generally considered by naturalists to be sessile; and if our observations were to be confined to certain *Macroura*, it would be difficult to disprove the assertion, since the distinction between eyes that are supported upon almost obsolete peduncles and those which have none is very limited.

---

the walking legs: hence *pereiopoda*. *Pleon* is taken from πλέω, *to navigate*, being that part of the animal which supports the limbs by which it swims about: hence *pleopoda*, the swimming feet.



A. Cephalon.
1. Eye.
2. Superior antenna.
3. Inferior antenna.
4. Mandible.
5. First maxilla.
6. Second maxilla.
7. Maxilliped.

B. Pereion.
8. First gnathopod.
9. Second gnathopod.
10 to 14. Pereiopoda.

C. Pleon.
15 to 20. Pleopoda.
21. Telson.

But in the larva of the Brachyura that we are now describing, the carapax is seen to pass distinctly round the base of the eye and the peduncle to be continued beneath the carapax, as in fig. B′, Plate XL. and fig. 1, B, Plate XLVI., and thus demonstrates the podophthalmic character of the larva even in this early stage.

The pair of appendages (Plate XL. figs. A and B, 2) first succeeding the eyes represent the anterior or upper antennæ. They respectively consist of a single articulation, narrowing towards the extremity, where are planted two short simple hairs, and two long almost invisible ones of the character that I have elsewhere* termed auditory cilia, since they are only found to exist upon the antennæ which support the acoustic organs. This fact enables us immediately to identify this immature appendage with the perfected structure, even at the earliest commencement of the young creature's life; and also demonstrates that the germ or rudiment of the filament, on which part only the auditory cilia are ever found, is present.

The second pair of appendages (Plate XL. fig. A and B, 3) represent the second or inferior antennæ, each of which in this stage consists of a basal articulation supporting a finely serrated spine, which is in fact a process of the same; and a flat, long, and squamiform articulation, ornamented at the extremity with two simple hairs, one longer than the other. At the base of these two appendages may be distinguished a small papilla—the germ of the future antenna (3 *a*).

The next succeeding pair of members are the mandibles (Plate XL. fig. B, 4). These differ from the adult organs in the absence of the appendage and the internal lever processes. In general form they manifest a striking approach in their present immature condition to those of *Talitrus* among Amphipoda (Plate XLVI. fig. 4 Q).

Posterior to these succeed the first pair of maxillæ (Plate XL. fig. B, 5), which consist of three squamiform plates, corresponding with those found in the adult, each capped with ciliated hairs, numbering about five or six upon the central or larger plate. These are stouter than on the other two, and approximate with increasing age more and more to the character of spines. They also increase in number.

The *second* pair of maxillæ (Plate XL. fig. B, 6) succeed immediately in position to the first, and in the earliest stage are developed upon the type of those of the adult. Each of them consists of three squamiform plates, equally divided at the apex, and fringed with plumose cilia. The plates are more uniformly equal than in the adult. At the base, the plate which homologizes with the flabella and branchia is present, and developed into a form that differs somewhat from, but probably fulfils the purpose of, an outletting valve at the anterior extremity of the branchial chamber, similar to the same organ in the adult.

The next succeeding pair of appendages should homologize with the maxillipeds, but these appear not to be present in this early form; and those which do follow are evidently, even at the present period, the immature form of the first pair of *gnathopoda* (Plate XL. figs. A and B, 8). Each of these last consists of a strong basal joint, which

* Annals of Natural History, 1854; Report on Edriophthalma, British Association, 1855.

supports two distinct appendages, the one consisting of five short articulations, the other of two long ones, terminating with four long finely-ciliated hairs.

The next pair of members differ little from the last, and represent the second pair of *gnathopoda* (Plate XL. figs. A and B, 9) in the adult. Like the preceding, each consists of a basal joint supporting two appendages, one of which is formed of three *short* articulations, the other of two *long* ones, furnished at the extremity with four long hairs delicately ciliated. At the base of these two last pairs of appendages, the germ of the future branchiæ may be distinguished. These two last pairs fulfil the office of natatory organs in this early stage of the animal.

Posterior to the last pair of members that I have described several sacs are visible Plate XL. figs. A and B, 10). These evidently contain the germs of the five pairs of *pereiopoda*, or true perambulatory legs, the most anterior of which I think I have been enabled to perceive lying folded within the sac, as shown in Plate XL. fig. 10. Some of these small sac-buds probably are the germs of the future branchiæ; and it is not improbable that in this embryonic condition they fulfil the object of their design sufficiently well for so immature a creature.

We now come to the third division of the animal, the *pleon*, or that portion which in adult Crustacea supports the swimming legs. It consists at this stage of six segments; five upon one type, the last different. The first five are simple articulations, and carry no developed appendage, except two small tooth-like processes upon the second. But close observation will detect the germs of the future *pleopoda* (Plate XL. fig. 17) upon one or two, situated laterally and inferiorly. Each of them consists of but a simple bud, on the margin of which can be detected three or four clear bead-like spots, the rudiments of the undeveloped cilia.

There are no data by which to determine the homologue of the two denticular processes (Plates XL. and XLI. figs. B, C‴, D″, 16) upon the second segment. They are directed forwards, and agree somewhat in position to the external organs of the adult male. They are constant upon all the specimens in this species, and in that of *Cancer Pagurus* also, the larva of which agrees so nearly with that of *Carcinus*, that it is doubtful if the closest observation could identify them apart. The *pleopoda* in an early stage are attached to all except the first and last of the segments of the *pleon*, but are present only in the adult female of the *Brachyura*.

If there be any truth in the hypothesis relative to the denticular processes upon the second segment, each animal must in its larval condition contain within itself the germs of both sexes. The one or the other becomes developed according to more or less favourable circumstances. If this be the case, it is not difficult to account for the occasional development of distinct sexes upon opposite sides of the same animal; or, as I have in my possession, a *Corystes cassivelaunus* bearing the aspect of the female, and yet possessing male organs.

The sixth or last appendage (Plate XL. figs. A and B, 21) to the larva homologizes with the last, or *telson* of the adult. It forms a prominently forked appendage, consisting of two

long slightly-curved styliform processes, armed upon the external margin with two or three teeth. Upon the inside, near the base of each, is a small lobe that supports three strong spinous denticulated hairs, and between the two lobes debouches the intestinal canal.

Having traced the structure of the individual parts of the larva as it exists immediately upon quitting the ovum, our next object will be to compare the same with others of later growth. Repeated moults, probably at intervals of seven or eight days, succeed each other, producing at each stage but little change to the eye but that of size. If we examine one probably a month old (Plate XLI. fig. C), it will be found to have acquired no distinct feature to mark it generally from the preceding. It has attained the length of two lines, that is, about as long again as the larva when it quits the ovum. The examination of individual parts will, however, exhibit some progress in the development of each member in relation to the whole.

The carapax differs not from that of the younger form, except that certain bead-like spots noticeable in the former have become developed into hairs in this. These exist mostly upon the long dorsal process and the posterior margin of the carapax. The eye has become more distinctly pedunculated, and appears capable of independent movement. The *anterior antenna* (Plate XLI. fig. C, 2) has the number of auditory cilia increased from two to eight or nine, and a small process (*d*) is discernible near the base of these cilia, which is evidently the secondary filament of the perfect organ. This goes on increasing with the succeeding moults. The stem of the organ exhibits a joint in the middle (Plate XLI. fig. D, 2), and the basal articulation considerably increases in diameter, so that before the animal throws off the larval condition, the anterior antenna has arrived at a point of development approximating to the character of the adult organ.

The second or posterior antenna (Plate XLI. fig. 3) likewise exhibits signs of progress. The squamiform (*g*) and spinous processes (*h*) are unchanged, but the small papilla at their base has increased, first to a length which scarcely equals that of the adjoining spine. In another moult it becomes longer (*f*, 3″). So it continues to increase, and with it distinct articulations, one probably being added at every moult.

The progress in the next succeeding pair (the mandibles, Plate XLI. D, fig. 4) is externally so little as to be scarcely appreciable. They appear more powerful in general structure, and the calcareous tendon and internal lever process can be detected by dissection.

The first pair of *maxillæ* (Plate XLI. D, fig. 5) have more cilia developed upon the margins of each plate; and a small lash (*z*) (the flabella of the adult organ) is likewise present; and it may be assumed, from the much greater relative size, that it fulfils a more efficient office in the larva than in the adult.

The second pair of *maxillæ* (Plate XLI. D, fig. 6) have likewise an increased number of ciliated hairs developed upon the margin of each plate; those upon the flabella have increased from four to a considerable number.

The next succeeding pair are still undiscoverable to the closest observation.

The two pairs of *gnathopoda* (Plate XLI. D, figs. 8 and 9) appear to have undergone

no change beyond an increase in their general size, and a little in the relative proportion of the appendages to the base on which they are supported, and the addition of a few hairs to the extremity of each.

We come now to that portion of the animal in which the greatest amount of progress is apparent. In the first stage we perceived a series of sac-like vesicles, the germs of the *pereiopoda*, which have since been gradually produced (Plate XLI. figs. C, 10 to 14), probably at the rate of a single articulation at every moult, since one or two are at first perceived, then more, and lastly the entire seven (figs. 10, 11′ and 11″). At the base of the legs the future branchiæ may be detected in the form of simple sacs. The anterior pair exhibit at this early date the chelæ of the adult organ.

The *pleon* (Plate XLI. fig. C″) exhibits the seven segments proper to the adult. This increase appears to have taken place by the bisection of the posterior segment, with which it continues in close connexion. The three central segments have at the posterior lateral extremities of each a strong tooth-like process, and upon the inferior surface certain oar-like appendages—the undeveloped *pleopoda*. These rapidly increase and have their margins—those which are anterior being the earlier—furnished with small dots, the germs of the future cilia. Upon the second segment (figs. C‴ and D″, 16), the two strong tooth-like organs projecting anteriorly and externally are still present.

The *telson* (C″ and D″, 21), or last segment, has lost some of the teeth with which the external margin was armed. Internally a few small hairs are added. The cleft between these appears less deep, and the styliform processes not quite so long.

Plate XLII. fig. E.—If we examine the growing animal after a few more moults, when it has increased to about three lines in length, we shall find its outline still holding a resemblance, though a less close one, to the previous appearance.

The form of the carapax scarcely differs except in the shorter relative length of the anterior and dorsal spines, and the whole animal appears stouter and more robust. The *gnathopoda* cease to be used as natatory organs; the *pereiopoda* are more fully developed, and assist in their proper capacity, and the *pleon* has lost its forked extremity.

Upon examining the several parts in detail, the organs are found generally to have progressed. The anterior antenna (fig. 2) differs scarcely from that in the adult. The posterior (fig. 3) has increased in length; the olfactory organ (*a*) is present in an immature form, and the appendages proper to the larval state are lost. The *mandible* (fig. 4) has assumed the form of the adult organ, and the appendage is present. The *maxillæ* (figs. 5 and 6) have progressed a little, but still retain some of their early conditions. The *maxilliped* (fig. 7), which is found wanting in the two preceding forms that have been examined, is now present, and differs in no very important feature from that of the adult. The *gnathopoda* (figs. 8 and 9) have considerably progressed, though they have not yet assumed (particularly the posterior) the form of the parent organ. The appendages on each have outgrown the basal articulation, which latter has sunk into an unimportant part. The first two joints have considerably increased, whereas the others, and their complementary appendage, appear not much changed.

The *pereiopoda* (fig. E, 10 to 14) have become organs sufficiently powerful to enable the animal to use them in walking. The anterior two or three pairs have a tooth-like spine attached to the anterior edge of the *coxa* and *basos*; and the branchiæ have assumed the compound character approaching that of the perfect organ.

The *pleopoda* (figs. 18, 19, 20) have all the external or secondary branches largely developed and furnished with plumose cilia, thus forming efficient natatory organs.

The *telson* (fig. 21) has no appendage. It is not forked as in the early period, but is imperfectly square and squamiform. On each side of the posterior margin the rudiment of the styliform process may still be observed in the form of a small denticle. The three central hairs still remain.

Soon other moults deprive the animal of the dorsal spine (Plate XLIII. F). But the loss of this peculiar feature in the external aspect of the animal, although the most apparent, is not, I think, the most important alteration at this period. The anterior margin of the carapax, including the rostrum, continues much depressed, but the lateral margin of the same anterior portion is much raised; there is also a considerable lobe (fig. F *a*, F″*a*) developed on each side posterior to the eyes. The *upper antenna* (fig. 2) is more complete, and the internal structure of the acoustic organ (fig. 2′) may be detected in the first articulation. The *second antenna* (fig. 3) has increased but little in length; and a few hairs, a pair of which are exceedingly long, are developed towards the tip. The *maxillæ* (figs. 5 and 6) are nearly of the same form and character as the preceding; so also are most of the succeeding members. Three small tubercles (*r*, *s*, *t*) are seen to be developed upon the oral margin of the posterior *gnathopoda* (fig. 9). The small protuberances, which were previously scarcely visible upon the *coxa* (*a*) and *basos* (*b*) of the anterior *pereiopoda* (figs. 10, 11, 12), have become developed into spines of considerable importance. The appendages (figs. 15 to 20) to the *pleon* have undergone no appreciable change. The *telson* (fig. 21) has lost the last rudiments of the styliform caudal processes; but the central hairs, still limited to three, remain as in the preceding.

Plate XLIV.—Successive moults rob the young animal soon of the frontal spine. Contemporary with its decreasing importance, the *pleon* becomes gradually folded nearer and nearer, until it is closely compressed against the inferior surface of the *pereion*. Upon each side of the carapax posterior to the eyes four small denticles (*l*, *m*, *n*, *o*) are developed. These at first are scarcely visible in the contour of the animal, which has considerably increased in diameter at this point, where it is as wide as at the posterior extremity of the carapax.

The eyes (fig. G, 1) are still large and prominent. The organs (figs. 5, 6, 7, 8, 9) attendant upon the mouth in all essential points approximate nearer to those of the adult form; and where there is a distinction, it is in their resemblance to the younger stage. The *pereiopoda* are all strong and capable of supporting the animal in its perambulations. The spines upon the *basos* in the *pereiopoda* are gone, and the *pleopoda* have lost their natatory character and assumed an atrophied appearance (figs. 17, 18, 19, 20).

When the animal is a little larger, though still of the same form, the segments of the *pleon* in the male commence a fusion together. The intromittent organs are visible.

The animal (exclusive of the *pleon*) scarcely differs in appearance from the time when it was half a line long until it has reached to two and a half lines; even then the alteration in appearance consists chiefly in the increase of the animal on each side, and the comparative shortening of the interocular portion of the carapax. The eyes are still prominent, but the organs generally have assumed a closer resemblance to those of the adult form, from which they appear to differ but little. That which is most conspicuous in the animal, exists in the gradual extension of the post-orbital or hepatic regions.

Having pursued the course of development from the larva to the mature form of the Brachyura decapod, a moderate-sized specimen of which produces about two millions of ova, we perceive that the progress made is not by any sudden metamorphosis, but by a series of moultings similar to those which take place in the adult; and that with each successive moult there is a corresponding degree of progress in its development. But the amount of change at each moult is so little, that it gives to the animal but a very small degree of difference in its general appearance; and it is only by a comparison of the earliest form with the last, and that without any consideration of the intermediate stages in its growth, that the idea of a true metamorphosis in decapod Crustacea has existed.

There are six or seven well-marked stages or forms that the growing animal passes through in its progress to maturity, and each of these is linked to the preceding, as well as to that which follows, by a succession of changes that are but just appreciable.

The form of the *Zoëa* when it first quits the ovum is distinctly embryonic. The whole of the parts are confined within a case, which gives it an immature character. The great dorsal and frontal spines are confined and folded close to the animal, and all the cilia enclosed within the tunic or outer case extend but a very limited way beyond that of the true limbs, whereas the greater portion of each is drawn back within it. This is correct of every member, and the large caudal spines upon the *pleon*. Besides this, the whole animal exhibits the appearance of contraction within the tunic, the skin being seen to be corrugated, so that when the animal throws off the case it immediately increases considerably in size.

It undergoes the first moult within a very few hours after its exclusion from the egg, when it loses much of its embryonic appearance, and swims about with more apparent control over its movements, and evidently seeks its own food. It keeps near the surface of the water, and always directs its head towards the light.

The large dorsal and frontal spines are extended, and exhibit a marked peculiarity in this stage of the young creature. The latter represents the rostrum, and is scarcely more important than is found among certain *Macroura*; whereas the former is occupied by the heart, and evidently homologizes with the pointed tubercle, which is situated upon the cardiac region in *Stenorhynchus*, &c. These two appendages gradually disappear, or to speak more correctly, their importance is outgrown by the relative increase of the

other parts, since they can be perceived in their position less and less prominent until the young creature has obtained the more important features of the adult. Looking at the carapax dorsally, it gradually increases in breadth from the extreme point of the frontal spine to the eyes, when, leaving orbits for the eyes, it widens a little immediately behind them, and then again it increases in diameter unto the posterior margin.

The larva, like the adult, has the power of elevating the carapax. The current of water that laves the branchiæ flows in beneath the posterior dorsal and lateral edges, while a membrane unites the centre of the carapax with the pleon, and precludes the admission of water to the internal viscera.

The larval form continues with a slight tendency to an increase in the relative length and width of the whole until the hepatic regions (Plate XLIII. fig. F*a*) become visible; and when these appear, the dorsal spine is lost, and the animal assumes the general aspect of a Decapod, approximating nearest in appearance to the form of the Spider-crabs among adults.

Soon after the hepatic lobes are visible, they become crowned first with one (Plate XLIV. G. *l*) anterior tooth, then two (*m*), three (*n*), and four (*o*). These ultimately increase in diameter and number, and become the latero-anterior denticulated margin of the adult *Carcinus*.

This margin on each side generally extends outwards and forwards, and the anterior tooth (*l*) becomes the outer limit of the orbit; while its under margin is formed by the carapax (fig. G″) being reflected inferiorly; its external limit, with the appendage which it supports—the second antenna (3),—being planted upon the inner side of the eye.

In the earliest form the eyes appear sessile. This, however, continues but a very little while. Before the animal has undergone a change in its general form, the eyes are elevated upon prominent footstalks. But even in its earliest stage this condition of the eyes is to our conception sessile, rather because the peduncle is limited, than because it is altogether absent. Thus in the genus *Cyrphiops*, DANA, of the southern seas, the eyes are hid entirely beneath the carapax, and in some of our (subterranean?) *Macroura* the peduncle is so short that the eye cannot readily be distinguished from the sessile form. This, which we find in the adult of different genera, is but a condition similar to that in the *Zoëa*. Thus in the *Macroura*, where the ophthalmic segment is absent, as I have observed in the young of *Crangon*, and has been represented in *Palæmon* by Captain DU CANE, the eyes are united at the base, as two organs springing from one origin; but in the *Brachyura*, where the ophthalmic segment is present,—though hid and very unimportant,—the eyes of the larva do not so closely approach each other; and, when seen dorsally (as in fig. B″, Plate XL.), exhibit evidences that they are actually pedunculated in this early stage*. With the development of these organs, the angle formed by the

* Since this paper has been laid before the Society, Mr. R. Q. COUCH has shown, in a paper read before the British Association at Dublin, and published in the 'Natural History Review' for October, 1857, that in *Palinurus*, in which the adult has the ophthalmic segment largely developed, the eyes in the larval condition are distinctly pedunculated.

reflexion of the carapax upon the inferior surface of the animal continues to increase, and, as previously shown, forms the orbit that protects the eye.

At first the *upper antenna* is embryonic (Plate XL. fig. 2) in its character, and bears a more imperfect appearance than is seen in any of the *adult* Crustacea, but approximates nearer to that of *Diastylis Rathkii* than to any of which we are aware. But, as we have before observed, there are conditions in the structure, even at this early period, which enable us not only to identify the organ with its homologue in the adult, but also to demonstrate the parts of it that are actually present.

In all adult Crustacea, as we have elsewhere shown*, the anterior antenna has upon each articulation of the filament two or more membranous hair-like appendages, which I have thought, from their being constant to the auditory antenna, and never found on any other part, to have an intimate connexion with the sense of hearing, and therefore call them *auditory cilia*.

When the animal throws off the earliest integumentary surface, there are but two of these *auditory cilia* visible; but their presence indicates not only that the organ is, as its position implies, the homologue of the anterior antenna, but that the germ of the future filament is present in a single articulation already developed. After several moults, two, three and more articulations appear successively, and a corresponding increase to the number of *auditory cilia*; and soon the germ of the secondary appendage is visible. We next perceive that the base of the organ has increased in diameter, and assumes a general form differing but little from that in the adult organ, and this while the animal is yet so young that it has lost nothing of its larval appearance.

In the mean time a corresponding change has taken place in the other organs. The second antenna is considerably produced in length, but as yet it has not assumed the form of the adult organ.

When first developed, as we have before seen, the second antenna consists of two branches springing from the same base. These branches we believe homologize with similar appendages to the adult organ, found mostly in the *Macroura* and *Anamoura* decapods. The true antenna springs from a small bud-like germ at their base (Plates XL. and XLVI. fig. B, 3).

The squamiform appendage in *Macroura* (the *Scaphocerite* of M. MILNE-EDWARDS's later writings) universally springs from the *basos* articulation; and therefore it is the homotype of the *exognathe* or palp, which springs from the same articulation of each of the posterior organs of the mouth, and therefore holds the same relation (as we hope shortly to demonstrate) to the more important parts in the young stage of the so-called natatory feet of the larva.

The antenna originating from the almost invisible germ (*a*) progressively developes, but its secondary appendages remain with each successive moult unaltered. They decrease in relative importance, and are ultimately lost, and this considerably before the animal has assumed the adult form. But it is interesting to observe that these

* British Association Reports, 1855.

embryonic appendages are most commonly present in the adults of the lower forms of Crustacea.

Perceiving the squamiform articulation to be common to the larva of *Macroura* as well as the *Brachyura*, we are enabled to identify it as the homologue of the same appendage in the adult *Macroura*, and to state that the articulation from which it springs is the homologue of the *basos* articulation of the adult. Unlike as is the earliest condition of the second antenna to the mature organ, yet before the larva has lost the dorsal spine it has assumed much the appearance of the fully developed state, and exhibits upon the *coxa* the yet imperfect stage of the olfactory organ, which shortly afterwards is protected by a strong operculum, that permits the internal organ to be exposed, or shut out from external sensations. Early in its existence this antenna is attached at the base only, but in the adult form the lateral portion of the carapax has so increased upon its structure, that the filamentary termination only extends free (Plate XLV. fig. 3. XLVI. fig. 3, J); the peduncle, except the last articulation, without being actually fused, is closely incorporated with the surrounding structure, and forms the internal wall of the orbit, and becomes the partition between it and the foramen in which the anterior antenna is planted.

The mandible (Plate XLVI. fig. B, 4) likewise undergoes considerable changes between the early and late conditions. At first there appears no internal lever or calcareous tendon, but it consists of a strong denticulated curved scale articulating with the integument. It bears a near resemblance to its homologue in the Edriophthalmous Crustacea (fig. 4 Q). It is without the (mis-named) palp*, which appears soon after and is produced contemporary with the internal continuation or lever of the organ.

The *maxillæ* (Plate XLVI. figs. 5, 6) differ but in the relative dimensions of their respective parts from those of the adult; and the first, like the mandible, bears an extremely close resemblance to that of the Amphipoda (fig. 5 Q).

The next pair of organs present in the adult are wanting in the larva of the *Brachyura*. These are the posterior cephalic appendages, and are developed only contemporary with the *pereiopoda*. The absence of these last appendages appears peculiar to the *Brachyura*. My own observations on the *Macroura* support those made by Captain Du Cane, M. Rathke, and M. Joly, who describe three pairs of natatory feet as belonging to the larva of the *Macroura*.

The two pairs of appendages present in the young *Brachyura* homologize with the two pairs of *gnathopoda* in the adult (Plate XLVI. figs. 8, 9, A to J).

If the animal be examined after a few moultings, it will be found, as previously described, that the *pereiopoda*, which can be detected immediately after birth, are developed directly posterior to those existing in the larva. These have also been perceived by Captain Du Cane in *Palæmon* in the same relative position. Examination of these members individually enables the relative character of each to be detected. The

* The so-called palp is the homologue of the continuous joints of the member, and not a secondary appendage, and probably represents the fourth, fifth and sixth segments of the true leg.

anterior pair become the cheliform organs, and therefore homologize with the first pair of *pereiopoda*, the large-clawed legs in the *Brachyura*.

This observation is not supported by the researches of Captain DU CANE on *Palæmon*; but I have, in the dissection of the larva of an unknown *Macroura*, removed the whole of the five pairs of *pereiopoda* from behind the larval appendages. Captain DU CANE's observations appear to have been conducted by watching the animal in its habits and parts without dissection. I therefore feel more confidence in my own observations, since, by removing every member, I could examine each as to its individual form. These remarks are also supported by the opinion of RATHKE, who states that the larval natatory appendages homologize with the "three pairs of maxillipeds" of the adult; that is, the posterior pair of the cephalic region, and the two anterior pairs of the *pereion*—"the *gnathopoda*." But, as I have previously stated, in the *Brachyura* the larva has but two pairs, and these homologize with the *gnathopoda* only.

Having established this position, we shall find that an examination of their development will confirm, by the forms that they assume, the correctness of these conclusions.

In the earliest form each of these organs consists of a *basal* articulation, that supports two separate appendages (Plate XLVI. figs. 8, 9, A). One, and this the more important (S), in this young condition exhibits alike in each pair but two articulations, the joint being only visible after being treated with liquor potassæ. The other appendage (T) differs in both pairs. It consists of five distinct articulations in the anterior (8), and but of three in the posterior (9). It is these two branches (T) that represent the true limbs of the adult. The others (S), without passing through any important change, become the secondary appendages in each.

There appears to be no very important alteration in the separate parts of the animal until the *pereiopoda* exhibit appearance of strength; but, in accordance with the changing condition in its habits from a swimming to a walking animal, the *gnathopoda* cease to be required as natatory organs: they consequently lose that power, proceed in the progress of their development, and assume that which enables them to fulfil the functions of external permanent organs attendant upon the mouth.

But the great distinction between the early and the late forms of the *Brachyura* is dependent upon the absence in the early stage of the *pereiopoda*,—the five posterior pairs of limbs belonging to the *pereion*.

In the early larva, when it has just escaped from the egg, the rudiments, undistinguishable without care, alone are present, in the form of sac-like appendages. After a few moults they are visible to casual observation, and increase gradually in size, joint by joint, until they are of sufficient importance to assist as organs of locomotion. Gradually, as this state becomes more perfect, the *gnathopoda* lose their natatory character, and assimilate to those of the mature animal.

Posterior to these there are no appendages in the larva, but the germs of the *pleopoda* are capable of being detected shortly after birth. These soon increase to their greatest comparative extent. At the same time, the *pleon*, which at first had but six segments,

has completed its number by the addition of one immediately preceding the *telson*. In the larva of the *Brachyura* this new segment forms no very important part in the general economy, since the appendages, which exhibit a prominent feature in the later stages of the young condition, again assume an atrophied condition. But in the *Macroura* the appendages of the penultimate segment increase to a very considerable degree at a very early period, and together with the last segment form the fan-like caudal apparatus of the adult. According to the statement of RATHKE, in the larva of the *Anomoura* the posterior *pleopoda* are early developed to a considerable extent. Thus at this immature age this intermediate form exhibits conditions of a mixed character. It has the *Macroura* type posteriorly, while anteriorly it exhibits that of the *Brachyura*, in having only two pairs of natatory feet in the earliest state.

But perhaps of all the parts in the *Brachyura*, the posterior segment or *telson* is that which undergoes the greatest visible alteration of form, passing, as it does in the larva of *Carcinus*, from a large fork-like appendage to that which is exactly the reverse. The *telson* of the adult terminates posteriorly in a blunt point fringed with hairs. But even this extreme alteration is but the result of a succession of gradual changes. In the *Macroura* the change from first to last is not so great. It is little more than an elongation, without a corresponding increase in the width of the segment.

In contemplating the development of the decapod Crustacea, from the youngest and most anomalous form to that of the adult, we perceive that the greatest amount of change, both in appearance and the development of parts, takes place in the *Brachyura*; but that even here the change is no sudden transformation of one form into another, but a gradual and persistent growth, following each successive moult. Every part that is present in the larva, though not permanent in itself, is to be found in a permanent condition in one or other form of adult Crustacea. And moreover, those appendages which play the most important parts in the larva, fulfil only secondary conditions in relation to the adult. Thus the large natatory limbs in the larva become the palps of the adult *gnathopoda*, and the appendages of the second antenna either represent unimportant parts of the same organ, or are altogether wanting. Again, we perceive that certain parts which continue present with but a small amount of alteration, such as the mandibles and the maxillæ, bear a close resemblance of form to the same organs in adult Crustacea of an order lower than the parent of these. Again, where development of new parts takes place, it follows a law that is in accordance with the absence or presence of the same parts in Crustacea in the descending grade. Thus we find that the posterior segments are those which are not present in the anterior and second division of the animal; but in the *pleon*, instead of being the last, it is the penultimate that is wanting.

Among the *Amphipoda* there are certain forms more or less perfect in their complete character. In the descending scale we perceive that the penultimate segment of the *pleon*, with its appendages, first becomes rudimentary, as in *Cyrtophium*, and ultimately disappears, as in *Dulichia*, before any other segments of the *pleon* are affected by the depressing change.

Perceiving that in its passage to maturity the larva of *Carcinus* passes through forms that are known to be adult, it is legitimate to infer that those forms hold a lower grade in the rank of perfect animals than the adult *Carcinus*. When it first exhibits conditions that approximate to the decapod character, it bears a very close resemblance to the triangular *Brachyura*. This gradually disappears with the development of the hepatic regions, and the constantly increasing resemblance to the form of the adult.

The *Leptopodiadæ* have generally been ranked by carcinologists as the highest of the crustacean type; but the similarity of their appearance to an immature form of the young *Carcinus*, is a circumstance that must induce the philosophical naturalist to reconsider the subject. It is not without a knowledge of the facts upon which zoologists have adopted the arrangement, that the above remark is made.

Carcinologists generally admit that consolidation of the nervous system is a marked elevation in the character of the animal, and Professor DANA has enunciated the doctrine, that "a centralization of the nervous ganglia is true cephalization."

It is true that in the Spider-crabs there exists no hollow space in the centre of the consolidated ganglia; but those which are thus consolidated homologize with the separate ganglia that supply the limbs of the animal with nerves, not with those ganglia that supply the organs that are endowed with the power of sensation.

This idea receives support from the known characters of the respective animals. The *Portunidæ*, of which the *Carcinus* is placed as the highest form, are active and vivacious creatures, whereas the *Leptopodiadæ* are inanimate and sluggish, fulfilling in their habits the existence of the fakirs of eastern tradition; they continue so long without movement, that weeds take root upon their surface, the growth of which prevents them from being distinguished from the surrounding objects.

Again, the general littoral character of the *Portunidæ*, and of *Carcinus* in particular—which differs not widely in form from the terrestrial *Gegarcinus*—together with the fact that all the *Leptopodiadæ* are deep-sea genera, is in accordance with the doctrine laid down by Professor AGASSIZ, that all land and freshwater animals assume a higher and more perfect form than their allied types of the ocean.

DESCRIPTION OF THE PLATES.

Fig. 1. The eye.
Fig. 2. Anterior antenna. 2′. Internal structure. *d*. Secondary appendage.
Fig. 3. Posterior antenna:—*a*. Permanent antenna. *g*. Squamiform process. *h*. Styliform process.
Fig. 4. Mandibles; Q. of Amphipoda. (*Talitrus*.)
Fig. 5. Anterior maxilla; Q. of Amphipoda.
Fig. 6. Posterior maxilla.

Fig. 7. Maxilliped.

Fig. 8. Anterior *gnathopoda*.

Fig. 9. Posterior *gnathopoda*. 9′. Point of ditto, to show the position of the cilia before the first moult.

Fig. 10 to 14. Pereiopoda:—*a*, Coxa; *b*, Basos; *c*, Ischium; *d*, Meros; *e*, Carpus; *f*, Propodos; *g*, Dactylus.

Fig. 15 to 20. Pleopoda.

Fig. 21. Telson. 21′. Exhibits the terminal process as folded within the outer case before the first moult. 21″. Ditto, undergoing change. 21‴. Ditto, undergone change.

S. Secondary appendage.

T. Principal appendage.

x, *y*. Branchia.

z. Flabella.

The numbers throughout refer to the same parts and represent the homological relation of each to the segment from which it is derived.

The small letters have also a similar value in relation to each individual part.

The Roman capital letters A, B, ... K, signify the stage.

PLATE XL.

Illustrations of the Development of Carcinus Mænas.

Fig. A. Larva immediately as it quits the ovum.

Fig. B. Larva after first moult.

Fig. B′. Cephalic region seen from front.

Fig. B″. Cephalic region seen from above.

PLATE XLI.

Fig. C. Larva after two or three moults.

Fig. D. Appendages of larva a little older.

PLATE XLII.

Fig. E. Larva after several moults, seen in profile.

Fig. E′. Ditto ditto, seen dorsally.

Fig. E″. Carapax seen from beneath. It has one eye, one anterior and one posterior antenna *in situ*.

PLATE XLIII.

Fig. F. Larva somewhat older than the preceding.
Fig. F′. Ditto ditto, viewed dorsally.
Fig. F″. Carapax with the eyes, one anterior and posterior antenna *in situ*, seen from beneath.

PLATE XLIV.

Fig. G. Larva as it approaches the character of the *Brachyura*.
Fig. G′. Carapax viewed from beneath.
Fig. G″. Carapax seen in profile.
Fig. H. Young *Carcinus*, approximating nearer to the adult form.
Fig. H′. Carapax seen from beneath: left anterior antenna removed.

PLATE XLV.

Fig. J. Adult *Carcinus*, viewed dorsally.
Fig. J′. Adult *Carcinus*, viewed ventrally.

PLATE XLVI.

Fig. K. Diagram illustrating the forms of the carapax in its passage from the larva to the adult *Carcinus*. Fig. A *et seq.* The progressive development of parts.

XXIX. *An Inquiry regarding the parts of the Nervous System which regulate the contractions of the Arteries.* By JOSEPH LISTER, *Esq., F.R.C.S. Eng. and Edin., Assistant Surgeon to the Royal Infirmary, Edinburgh. Communicated by Dr.* SHARPEY, *Sec. R.S.*

Received June 18,—Read June 18, 1857*.

GREAT light has been thrown in recent times upon the nature of the influence exercised over the blood-vessels by the nervous system. In 1852 it was shown by M. BERNARD that division of the sympathetic nerve in the neck of a cat, or other mammalian, was followed by turgescence of the blood-vessels of the ear, and increased heat of that part and of the whole side of the face, together with contraction of the pupil. Early in the following year Mr. AUGUSTUS WALLER performed the converse experiment of galvanizing the sympathetic above the point where it had been cut or tied, with the very striking result of rapid subsidence of the turgescence of the vessels, and fall of the temperature of the face; while the pupil became so extremely large, as to imply that the dilating fibres of the iris were thrown into a state of energetic contraction†.

From these experiments it appeared to follow pretty clearly that the sympathetic nerve in the neck presides over the contraction of the vessels of the face, which, becoming relaxed and dilated when the influence of the nerve was removed by its division, allowed the blood to flow through them in larger mass than before; but on the other hand, when excited to extreme constriction by the galvanic stimulus applied to the nerve, permitted but little blood to pass. This conclusion appears to be confirmed by the observation since made by BROWN-SÉQUARD, that the elevation of temperature which occurs in BERNARD'S experiment is never greater than is to be accounted for by the increased mass of warm blood which must be sent through the part, on the hypothesis that the turgescence of the vessels is simply the result of their dilatation. It was further shown by MESSRS. WALLER and BUDGE, that the same region of the spinal cord which they had previously ascertained to preside over dilatation of the pupil, namely, the part included between the last cervical and third dorsal vertebræ, also regulated the vessels of the face. When that part of the cord was removed, turgescence of those vessels occurred; but galvanizing the anterior roots of the spinal nerves proceeding from

* This paper, and that on the Pigmentary System of the Frog, were read as supplements to the Essay on the Early Stages of Inflammation which succeeds them. The author has since extended his investigations into the subject of the present memoir, in accordance with a recommendation from the Council, and the results have been incorporated into the text, all new matter thus introduced being indicated as such either by date or by note at the foot of the page.

† Comptes Rendus, vol. xxxvi. p. 378.

that part produced the same effect as irritation of the sympathetic, namely, pallor with diminished temperature*. M. SCHIFF afterwards ascertained, that after destruction of the lower part of the cervical and upper part of the dorsal region of the cord in Bats, there is an immediate dilatation of the small vessels of the wings†, and BROWN-SÉQUARD had previously shown that after transverse section of the spinal cord in the lumbar region in Birds and Mammals, an increase of 1°, 2°, or 3° FAHR. took place in the temperature of the paralysed parts‡. All these facts tend to the same conclusion, namely, that the spinal cord is the part of the nervous centres which presides over the blood-vessels, and that one important action at least which it induces in them is constriction of the circular coat of the arteries. But there still remains, I believe, some difference of opinion with regard to the interpretation of BERNARD'S experiment; and there might be some colour for the idea that the red and turgid state of the vessels seen after division of the sympathetic in the neck was due to a change in the blood, such as occurs in inflammation, and that the pallor ensuing upon galvanizing the nerve was the result of a return of the vital fluid to its normal condition after restoration of nervous influence. But all ambiguity of this kind seems to me to be removed by some observations made several years ago by Mr. WHARTON JONES upon the Frog. This animal is peculiarly adapted for investigations on this subject, because both the calibre of the vessels and the state of the blood as it flows through them can be observed with the utmost facility in the web; and Mr. JONES found that division of the sciatic nerve was followed by dilatation of the arteries, but that this increase of calibre, so far from being caused by an obstruction in the progress of the blood, was accompanied with unusually free and rapid flow through the capillaries§. But with regard to the part of the nervous system which regulates the contractions of the arteries, some more recent observations by the same author are at variance with the conclusion above drawn from experiments by others upon Mammalia. For he states that the division of the roots of the sciatic nerve within the spinal canal failed to produce dilatation of the vessels; whence it was inferred that the sympathetic fibres of the sciatic trunk, as distinguished from those derived from the cord, are the channels through which the stimulus is transmitted to the arterial coats‖. WALLER and BUDGE'S experiments, on the other hand, appear to show that it is from the cord that the sympathetic derives its controlling power over the arteries. This discrepancy upon a matter of such great importance in physiology appeared to me to demand further inquiry¶, and I propose in the present paper to communicate the results to which this investigation has led.

* Comptes Rendus, vol. xxxi. pp. 377, 575.

† Gazette Hebdomadaire de Med. et de Chir. 1854, pp. 421, 424.

‡ Experimental Researches, New York, 1853, p. 8.

§ Essay on the State of the Blood and the Blood-vesselsin Inflammation, by T. WHARTON JONES, Esq., F.R.S. Guy's Hospital Reports, vol. viii. p. 12.

‖ Observations on the State of the Blood and the Blood-vessels in Inflammation, Med. and Chir. Trans. vol. xxxvi.

¶ Since this paper was read, my attention has been called by Professor GOODSIR to experiments recently

The first experiment which I performed with reference to this subject (October 27, 1856), namely, division of the sciatic nerve on one side, gave somewhat puzzling results. Knowing how difficult it is to judge correctly of differences of calibre in the vessels by mere inspection, I tied out both feet of a frog (under chloroform), so that a slight movement of the stage of the microscope would bring either into view, and thus, after performance of the operation in one limb, the other foot might serve as a standard of comparison. I then selected a particular artery of the left foot for measurement with the eyepiece micrometer, and, having noted the limits between which its calibre varied during half an hour, isolated the nerve from surrounding parts by dissection, without any material change taking place in the diameter of the vessel. I next tied a piece of thread tightly round the nerve, with the effect of causing within the first few seconds distinct constriction of the artery, which then gradually expanded, and within two minutes had a larger measurement than I had previously observed. In other words, the effect of the ligature had been constriction speedily followed by dilatation. But on examining the web half an hour later, I found the artery had contracted again to about its usual proportions; after a few minutes the amount of constriction was very considerably greater, and continued so after division of the nerve above the ligature, and on looking at the other foot I found the arteries there similarly contracted. During the next twenty-four hours I made frequent careful comparisons of the conditions of the arteries in the two feet, and found that they presented exactly the same variations in calibre; being sometimes closely constricted, at other times fully dilated in both. The constrictions generally commenced a very short time before a struggle of the animal, and gradually subsided when it had become quiet. It was thus evident that the arteries had experienced no permanent dilatation whatever from the division of the sciatic nerve, a result quite at variance with the experience of previous observers.

The explanation of this will shortly appear. On the 8th of April, 1857, I laid open the spinal canal of a frog in its entire length, and divided, as I supposed, all the roots of the nerves coming off from the left side of the cord from the occiput to the sacrum, and immediately examined the webs of both feet, the frog being under the influence of chloroform. In the right limb the circulation was almost entirely arrested, while in the left it was going on freely. My attention was then diverted for half an hour, when the arteries of the right foot were found of medium size; but in all the three webs of the left foot they were extremely dilated, appearing to have two or three times the diameter of those of the right limb *. This observation was of itself sufficient to prove that the

performed by Pflüger. Operating upon the large edible frog of the continent (*Rana esculenta*), he succeeded in applying the galvanic stimulus to the anterior roots of the sciatic nerve within the spinal canal, with the effect of causing complete constriction of the arteries of the webs. Division of the same roots on the other hand was followed by full dilatation of the vessels (see Henle and Meissner's Bericht, 1857). Clear proof had thus been given, before my investigation of the subject commenced, that the spinal system does influence the arteries of the frog's foot.

* In this and other cases of division of roots of the spinal nerves, I observed that the skin of the limbs supplied by the nerves cut became perfectly smooth, instead of being, as usual, rough with minute papillæ. This appears to show that the unstriped muscular tissue of the skin is under the control of the spinal system.

spinal system, as distinguished from the sympathetic, does influence the contractions of the arteries of the frog's foot. Here, however, as in the case of the divided sciatic nerve, the effects were not permanent. Six hours later the arteries on the left side appeared smaller than they had been, though still bearing marks of the operation by remaining constant in calibre, whereas those of the right foot exhibited very frequent variations, from pretty full dilatation to almost absolute closure. Next day the same state of things continued, the vessels of the left foot being constant in size for four minutes together, while in the right foot an artery exhibited about eight distinct variations of calibre per minute as observed by micrometer; but after three days more they had become both small and variable in the left foot, and seemed to have quite recovered. On the application of galvanism to the cord, however, both legs were thrown into violent spasm, showing that communications still existed between the left limb and the nervous centre; and it appeared probable that the branches which remained undivided had come after a while to supply more or less perfectly the place of those which had been cut. A similar explanation seemed applicable to the speedy recovery of contractility in the vessels after cutting the sciatic, other nerves in the limb supplying the place of the divided trunk.

In another experiment, performed on the 11th of April, the roots of the nerves on the right side were divided within the spinal canal, beginning at the head and proceeding gradually backwards. No enlargement of the vessels of the webs occurred until the roots of the sciatic plexus were cut, when full dilatation of the arteries of the right foot took place, one which had a few minutes previously varied from 1 to 2 degrees of the eyepiece micrometer being now $3\frac{1}{2}°$ in diameter, and remaining so for ten minutes together. Half an hour later, however, I was astonished to find the artery again contracted to 2°, and not quite constant in calibre. But next day, on dissecting the animal, I found that some branches of considerable size between the cord and the sciatic plexus remained entire.

This experiment, while confirming the proof of the influence exerted by the cord over the arteries of the feet, convinced me how difficult it is to make sure of dividing all the roots of the nerves for the hind legs within the spinal canal; the operation being a very delicate one, while the parts are obscured by the bleeding which occurs in the living animal. At the same time the speedy recovery of function after partial division of the roots, pointed out a ready source of fallacy in such experiments. Had I deferred the examination of the web for half an hour in this case, there would have been no evidence of any effect produced on the vessels by the operation, and yet, had it not been for dissecting the frog, I should not have doubted that all the roots had been severed.

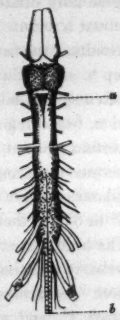
Dilatation of the vessels of the webs having been found to follow division of the roots of the spinal nerves, it appeared important, in order to complete the evidence on the point at issue, to observe the occurrence of contraction in the arteries on irritation of the cerebro-spinal centre. For this purpose, on the 14th I laid open the cranium of a frog under chloroform and thrust a very fine needle into the cerebral hemispheres, while one of the feet was stretched under the microscope: no effect was, however, pro-

duced upon the arteries; one selected for micrometrical observation, the largest of the web, measuring, as it had done before, nearly 4°, which was a state of full dilatation. I then treated in a similar manner the posterior dark-coloured portion of the brain, including the optic lobes, cerebellum and medulla oblongata, which were not distinguished from one another in the experiment. As I continued this treatment for a few seconds, keeping my eye over the microscope, the artery became contracted to 1°, which was the length of a red corpuscle. The leg then became spasmodically extended, and the artery was carried out of the field; but when I next looked at the web after removal of the needle, the vessels had dilated again to pretty full size. Having selected a main artery of another web more conveniently placed, I repeated the experiment of thrusting the needle into the posterior portion of the brain. This vessel, which just before, though by no means at its largest size, measured 2½°, became contracted to almost absolute closure, and remained so till the needle was removed, after which it gradually dilated, and in three minutes measured 2°; forty seconds later 2½°; and about a minute afterwards 3°. The experiment was repeated several times with similar results, "the invariable rule" (to quote from my notes) "being contraction of the artery up to a certain point, and maintenance in the contracted state during the *whole* time, often several minutes, that the needle was stirred about in the brain; and then expansion, beginning almost immediately after withdrawal of the needle, and advancing to a certain point at which it remained till the needle was again introduced." As the brain became more and more broken up, the contractions grew less and less energetic, and the dilatations were increased, till the needle failed to produce greater contraction than from 4° to 3°. I then thrust the needle into the spinal canal and withdrew it immediately. The hind legs started, and, after a few seconds, when I first caught sight of one of the webs, it was almost bloodless, and the arteries were invisible through extreme constriction. Four minutes later the artery before observed had begun to dilate and measured 1°, and after five minutes more it was 3°. A repetition of this experiment produced similar effects*.

* The constriction of the arteries of the webs on irritation of the cord may be readily demonstrated in the following simple manner. The head of the frog being depressed so as to stretch the ligament between the occiput and first vertebra, a sharp knife is carried across the spinal canal immediately behind the head, so as to divide the cord from the brain. The toes may now be tied out and any observation made upon the web without the inconvenience generally produced by voluntary struggles on the part of the animal, while at the same time the use of chloroform is avoided; which is very desirable, on account of the irritating effect of its vapour on the web and the constant care required for its administration. If the webs be examined immediately after the operation, they will be found exsanguine from extreme constriction of the arteries; but in a few minutes this state will give place to dilatation with free flow of blood. If now a fine needle, curved at the end, be introduced through the wound into the spinal canal, so that its point may penetrate a short distance into the cord, while the eye of the observer is kept over the microscope, the arteries will be seen to become constricted to absolute closure, and dilate again after withdrawal of the needle. The experiment may be repeated as often as may be desired till the cord becomes disorganized.

I have lately found the above-mentioned mode of preparing the frog the best adapted also for experiments

Abundantly sufficient proof had now been obtained that the cerebro-spinal axis does contain a nervous centre for regulating the contractions of the arteries of the feet. But it was uncertain whether that centre were confined to any one part of the cord, or diffused extensively through it and the brain; or even whether a similar office might not also be discharged by some of the sympathetic ganglia. With a view to determining these points, which are of great physiological interest, several experiments were performed, some of which it will be necessary to relate; but in order to make their description intelligible, it will be well to say a few words regarding the arrangement of the spinal cord in the frog. It does not occupy the entire length of the spinal canal, but extends backwards only seven-tenths of the distance from the occiput to the sacrum, while the posterior three-tenths of the canal contain merely the cauda equina, including a slender filiform prolongation of the cord, which, though apparently composed in part of nervous matter, seems to give off no nerves.



In the accompanying sketch of the superior aspect of the brain and cord of a frog, magnified two diameters, the distance from *a* to *b* represents the length of the spinal canal. The principal nerves for the hind legs spring from the cord near its extremity, but other smaller branches with the same destination arise nearly as far forward as the middle of its length. There are also connecting filaments between these and some nerves for the abdominal parietes, taking origin slightly further forward than the middle of the cord. Thus the nerves for the posterior extremities are furnished chiefly, but not quite exclusively, from the posterior half of the cord. To expose the cord in its entire length without injury to it or any of its slender branches is troublesome, and also involves much loss of blood. It is therefore very desirable to be able to come at once on any part of the cord you may desire, without laying open the whole canal. This can be readily done from the data above given. The articulation between the occiput and first vertebra can be felt through the skin, as also can the commencement of the sacrum; and the distance between these points is the length of the spinal canal. This, multiplied by 0·7, is the length of the cord: the requisite fraction of this length is then measured from the occiput and gives the place required.

Assistance may also be derived from the circumstance that the posterior edges of the scapulæ correspond very nearly with the mid-length of the cord, overlapping the posterior half by only about $\frac{1}{10}$th of the whole.

To proceed with the experiments. On the 16th of April, a large frog being put under chloroform, the entire brain was removed about 3 o'clock P.M. without injury to the cord. After this operation, the arteries, which had previously been of pretty full size

elucidating the nature of inflammation. Little if any reflex action of the limb occurs when irritants are applied to the web; and if no great amount of blood have been lost in the operation, the creature will survive it a long while, *e. g.* eight days in one case.

and transmitting rapid streams of blood, were found completely contracted, so that the webs appeared bloodless except in the veins, and continued so for some minutes. At $3^h 10^m$ an artery selected for special observation was dilating, having already attained to a diameter of $1\frac{1}{3}°$, and the circulation was returning in the web. At $3^h 15^m$ the vessel measured 3°, but two minutes later was $2\frac{1}{2}°$, and half an hour afterwards exhibited the spontaneous changes in calibre commonly seen in arteries in health, the limits observed being $1\frac{1}{3}°$ and 2°. It thus appeared that the removal of the brain had had no further effect upon the arteries than the temporary constriction induced by the irritation of the anterior part of the cord in the operation, followed by a brief period of dilatation. At 4^h, a small part of the spinal canal having been laid open, the anterior sixth of the cord was removed, corresponding to the anterior third of the scapulæ. At $4^h 3^m$, when the web was first looked at, the artery was contracted to absolute closure, and the web exsanguine; and this state of things continued till $4^h 7^m$, when the vessel began to dilate. At $4^h 8^m$ it measured $2\frac{1}{2}°$, and at $4^h 13^m$, 3°. Four minutes later it was short of 3°, and after five minutes more it was observed to be undergoing spontaneous variations of calibre from $2\frac{1}{2}°$ to $2\frac{2}{3}°$. Finally, at $5^h 30^m$ its condition was just as it was before the experiment was performed, varying from $1\frac{1}{2}°$ to 2°, without any struggle on the part of the creature, the blood at the same time flowing rapidly through it*. At 6^h, another vertebral arch having been taken away, the subjacent portion of cord was removed, the canal being thus cleared as far back as the level of the mid-scapulæ, corresponding to rather more than a quarter of the cord. The operation caused contraction of the artery to 1°; but this passed off in half a minute, and was followed by no further dilatation than to $1\frac{1}{3}°$, and a few minutes later the artery was again spontaneously varying from 1° to $1\frac{1}{3}°$; at the same time the heart's action was somewhat enfeebled. At $6^h 15^m$ the portion of cord corresponding to another vertebral arch was cut away. The operation induced contraction from $1\frac{1}{3}°$ to $\frac{1}{2}°$, followed by gradual dilatation (in fifteen seconds) up to $1\frac{2}{3}°$, and this, in a few seconds, gave place to spontaneous contraction to $1\frac{1}{2}°$. By this last operation the vertebral canal had been cleared as far back as the posterior third of the scapulæ, corresponding to between one-third and one-half of the length of the cord.

At $6^h 30^m$, having removed another vertebral arch, I divided the cord imperfectly, as far back as it was exposed, namely, at the level of the posterior edges of the scapulæ, which is in the commencement of the posterior half of the cord; and on looking at the web twenty seconds later, found the artery undergoing oscillations in calibre, such as had never before been seen in it, contracting and dilating distinctly five times in a minute, from 1° to $1\frac{1}{3}°$ or $1\frac{1}{2}°$. At $6^h 32^m 20^s$ the cord was cut fairly through at the point indicated, without removal of the segment from the canal, and at $6^h 34^m$ the

* The transient character of the effects produced upon the arterial calibre by these operations, led me at first to conclude that the anterior parts of the cerebro-spinal axis did not contain any nervous centre for the arteries, and this view was expressed in the original manuscript. My opinions on this point have, however, been altered by the results of subsequent experiments, as will appear at the conclusion of the paper.

artery was found quite constricted and the web exsanguine. At 6^h 36^m 10^s the artery had somewhat dilated, and measured $1\frac{1}{3}°$, but the blood was moving very slowly through the vessels, the heart being evidently exceedingly enfeebled. At 6^h 40^m the portion of the cord was detached from the roots of the nerves which sprung from it and removed from the canal, immediately after which the artery was found dilated to $1\frac{2}{3}°$, but the blood had ceased to move in consequence of the feebleness of the heart.

The experiments upon this animal show that if the brain and anterior third of the cord act at all as nervous centres for the arteries of the feet, they are certainly not the only parts which possess that function; and also, that irritation of any part of the anterior half of the cord gives rise to contraction of the arteries of the webs, followed by dilatation, varying much in extent and duration, but generally proportioned in both respects to the previous constriction. It is probable that the dilatation would have been greater after the last operations, had the heart been working more powerfully; for it will hereafter appear that a certain amount of distending force on the part of the blood is necessary for the vessels becoming fully expanded.

On the 18th of April, having put a large frog under the influence of chloroform, I removed a vertebral arch opposite the junction of the middle and posterior thirds of the scapulæ, and then cut across the cord in that situation, *i. e.* rather more than a line anterior to its middle; a slight retraction of the two segments proved that the division had been thoroughly effected. This was at 10 o'clock A.M. A few minutes later the arteries had recovered from the effects of the irritation; one selected for special observation, having measured $1\frac{2}{3}°$ just before the operation, now varied occasionally between $1\frac{1}{3}°$ and $1\frac{2}{3}°$, and the circulation was rapid through the vessel. The next vertebral arch posteriorly having been removed, the cord was divided as far back as it was exposed, at 10^h 23^m 50^s; immediately after which the web was found exsanguine in consequence of complete closure of all the arteries, which continued almost in the same condition for ten minutes, at the end of which time the artery selected was still so small as to transmit single corpuscles with difficulty. At 10^h 35^m the portion of cord included between the points of section was detached from the roots of the nerves connected with it and removed from the canal. It measured nearly a line in length, and the posterior segment thus shortened proved afterwards to be only a very small fraction more than half the length of the cord. The vessels afterwards relaxed slowly, so that at 10^h 37^m the corpuscles were passing a little more freely through the artery. At 11^h 15^m the artery measured $1\frac{1}{2}°$, but transmitted the blood in a very languid stream; and at noon the evidences of circulation were so equivocal, that I suspected the creature, which was weak to begin with, to be dead, though this afterwards proved to be a mistake. At 0^h 45^m P.M. the same state of things continued, and the artery still measured $1\frac{1}{2}°$, having remained unaltered in calibre for the last hour and a half; but I determined to try the effect of irritating the posterior segment of the cord, and introduced the point of a needle a short distance into its anterior extremity and withdrew it immediately, keeping my eye over the microscope. The effect upon the artery was immediate constriction, causing a retro-

grade stream of the blood in it for about a second, and then absolute obliteration of calibre. At $0^h\ 49^m$ the artery allowed single corpuscles to pass through it with considerable difficulty. At 1 o'clock the arteries of the web were still small, but I noticed that they were undergoing very remarkable oscillations in calibre, just as occurred on one occasion in the frog last operated on, but in the present case they were more striking. I noted the variations for some time, and give in the following Table a specimen of those which occurred during one minute:—

	h	m	s		
At	1	2	57	the diameter of the artery was	$1\frac{1}{4}°$
At	1	3	9	the diameter of the artery was	1
At	1	3	20	the diameter of the artery was	$\frac{1}{2}$
At	1	3	25	the diameter of the artery was	0
At	1	3	38	the diameter of the artery was	$\frac{1}{2}$
At	1	3	45	the diameter of the artery was	0
At	1	3	50	the diameter of the artery was	$\frac{1}{2}$

These oscillations continued for upwards of half an hour, but during the latter part of that time the extreme degrees of constriction were not observed.

At $1^h\ 43^m$ P.M. I raised the vertebral arches from the end of the spinal canal, and removed the posterior half of the cord together with the cauda equina; immediately after which, the artery, which for the last hour had not exceeded $1\frac{1}{4}°$, became expanded to $2\frac{1}{4}°$, a dimension which it had never before been observed to attain, except during the secondary dilatation that ensued after the first division of the cord when the heart was in powerful action. All the other arteries of the web became dilated at the same time, and remained of perfectly constant diameter during the hour that I continued to observe them. Finally, at $2^h\ 40^m$ I introduced a needle into the anterior part of the spinal canal which had hitherto been undisturbed, and irritated both the anterior portion of the cord and the brain, but no effect whatever was produced upon the vessels.

The constriction of the arteries, which resulted in this case from irritation of the posterior half of the cord isolated from the rest, and the permanent dilatation which ensued on removal of the same part, prove that this portion of the cerebro-spinal axis certainly contains a nervous centre for regulating the contractions of the arteries of the feet. The frequently alternating contractions and dilatations which occurred in this animal, as well as in the last, after irritation of the posterior half of the cord, are curious, and may perhaps be considered analogous to rapid action of the heart under the influence of stimulus. The fact that the arterial contractions so constantly observed to result from irritation of the anterior part of the cord, while it retains its connexion through the rest of the cord with the roots of the nerves of the hind legs, fail to occur after removal of the posterior two-thirds of the cord, has been confirmed by subsequent experiments upon other frogs. It appears to imply that if the brain and anterior part of the cord discharge the functions of a nervous centre for the arteries of the feet, they do not exert

that influence through the branches which connect them with the sympathetic, but only through the roots of the nerves given off from the more posterior parts of the cord.

On the 2nd of June, a large frog having been put under the influence of chloroform, the vertebral arches were removed, from the sacrum to the posterior edges of the scapulæ, and at 0^h 30^m P.M. the cord was divided immediately behind the latter situation, *i. e.* a little behind its middle. The left foot being examined shortly after, the arteries were seen to be considerably constricted; one of them, which appeared to be a principal trunk, permitting single corpuscles to pass with difficulty, and the contraction became extreme after irritation of the posterior segment of the cord with a needle. The whole of the exposed part of the cord and the cauda equina, including the chief branches of nerves for the hind legs, were then removed (at 0^h 56^m), and when the foot was again looked at, at 1^h 10^m, the circulation, which had been previously entirely arrested by the contraction of the vessels, was going on rapidly through dilated arteries, the one before mentioned now measuring 3°. This, however, proved not to be the extreme degree of dilatation of which the vessel was capable; for a stream of water at about 120° FAHR., thrown for perhaps a second upon the foot, induced, after brief imperfect contraction, an expansion to nearly 4°, which again was followed after a few minutes by a return to 3°. This experiment was several times repeated. In the right foot, which had not been subjected to the hot water, though necessarily equally affected with the other by the removal of the portion of cord, the arteries were found of moderate size at 3^h 45^m, having evidently recovered, to a considerable extent at least, their contractile power during the $2\frac{3}{4}$ hours which had elapsed since the operation. One which at this time measured $1\frac{2}{3}$°, became dilated on the application of hot water to 3°, and afterwards contracted spontaneously to 2°.

At 4^h 15^m an additional portion of the cord was removed, so as to clear the spinal canal as far forward as the anterior third of the scapulæ. The arteries became at once dilated to some extent, notwithstanding that the heart's action was greatly enfeebled by this operation; and at 6^h 45^m they had attained nearly the full diameters that the hot water had before induced, while the circulation had somewhat recovered. Next morning the arteries of the two feet, the dimensions of which were before given, measured 4° and 3° respectively, and they continued without the slightest variation until 5^h 25^m P.M.; the circulation meanwhile had continued to improve, and was healthy, though still languid. I then removed the remainder of the cord and the entire brain without producing any effect whatever on the size of the arteries, and they still measured precisely the same at 10^h 45^m P.M. The following morning the frog was dead, and the tissues of the web had become opaque by the imbibition of water.

In this case the arteries recovered their contractile power after the removal of the greater part of the posterior half of the cord, together with the chief roots of the nerves for the hind legs; but when the part which furnishes branches to the posterior extremities had been completely removed, the arteries became permanently dilated; and, though

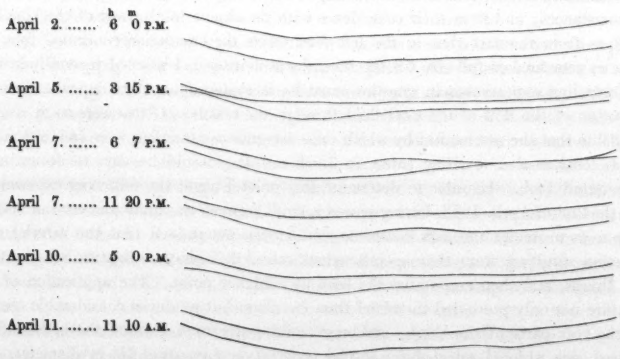
the circulation was then feeble, soon attained the full calibre which hot water had induced at a time when the heart was in powerful action.

The perfect constancy with which the vessels observed maintained these dimensions for more than thirty hours after the operation, implied that they were not then at all acted on by the nervous system; and hence I was led at first to infer that there existed no other ganglionic apparatus for the arteries of the feet than that contained in the cerebro-spinal axis*.

I have since witnessed in other frogs the permanence of the dilatation of the arteries after removal of the brain and cord. The following case, however, appeared at first inconsistent with these observations. On the 23rd of October the brain and cord of a large frog were completely removed, and an operation was performed upon the right thigh, which, as it turned out, tended to interfere with the freedom of the circulation in the webs; so that after twelve hours, the blood, though not presenting the appearances of inflammation, was almost motionless in that foot. At the same time, two arteries in one of the webs, which had till then remained perfectly constant in calibre, as determined by micrometer, began to exhibit variations, and during the next twenty-four hours continued to change their diameter occasionally. There were, however, certain peculiarities about these changes such as I had never before seen. Generally speaking, all the arteries of a web are found in the same degree of contraction at any one time; but here, one of the vessels under observation was sometimes small, when the other, though in the same web, was large; and not only was there no proportion between the degrees of contraction in the two vessels, but in one and the same artery the amount of constriction was very different at different parts. The unusual character of these contractions implied that they were caused by some unwonted circumstances; and from their coincidence with the almost total arrest of the blood, as well as from the fact that in the left foot, where the circulation continued free, the arteries remained of full size till the animal was destroyed, I was led to conclude that the puzzling appearances in question must be in some way or other dependent on the cessation of the flow of the vital fluid through the vessels. If this were so, it seemed probable that the mechanism by which these irregular contractions were induced might be as local as their exciting cause, in which case they would be seen to occur in an amputated limb. In order to determine this point I made the following experiment. On the 2nd of April, 1858, having passed a knife between the brain and cord of a large frog so as to render the legs insensible, and having ascertained that the arterial constriction resulting from that operation had subsided, I placed a ligature round one of the thighs, and then amputated the limb at a higher point. The application of the ligature not only prevented the blood from escaping, but produced considerable tension in the soft parts of the thigh; and on examining the webs, I found the arteries fully dilated, one which I selected for special observation measuring $4\frac{1}{2}°$ in diameter. At

* This was the view expressed in the original manuscript, but it has been since modified by further experiments mentioned in the text, made, as their dates imply, subsequently to the reading of the paper.

6^h P.M., an hour and a half after the amputation, the vessel still maintained the same calibre, but at 7^h 35^m it was slightly less, viz. 4°, which was still its measurement at 11 o'clock. Hitherto no change distinctly referable to vital contractility had taken place, but on the following morning the vessel was reduced to 3° in diameter, and on the 4th of April it was of different sizes in different parts, viz. from 1½° to 3°, and varied somewhat during the course of the day. Still more striking changes in the diameter of the artery appeared on subsequent days; thus the vessel was sometimes constricted to absolute closure in one part of its course, and dilated to a very considerable degree, *e. g.* 3½°, in another part. More commonly, however, the artery, though never uniform in size as in health, had a general tendency either to moderate constriction or dilatation. The variations occurred frequently during the twenty-four hours, and on one occasion I saw the artery in the act of slow contraction at one part driving the blood into a dilated portion at a little distance. So late as the evening of the 10th of April, *i. e.* during the ninth day after amputation, far later than vital contractility is generally believed to last in a limb so circumstanced, variations of calibre continued to show themselves; but on the 11th of April the vessel had an almost uniform width of nearly 3°, and exhibited no variations, while, at the same time, other evidences of loss of vitality in the tissues began to show themselves. The accompanying outlines of the calibre of a limited portion of the artery, which was the subject of special observation, have been made from micrometrical measurements selected from among a large number daily registered. They will serve to convey an idea of the more striking varieties of appearance presented at different times. It may be mentioned, that the diameter of the vessel, when most dilated, was about 4½ times the length of a red corpuscle of the frog's blood.



It must be added, that the limb was kept wrapped in clean wet lint in a cool place in the intervals of the observations, and that during the periods of examination care was

taken to guard against warmth or dryness, or any other agency calculated to injure the delicate tissues of the webs.

Thus irregular contractions, precisely similar to those which accompanied local arrest of the circulation in the experiment of October 23rd, took place in consequence of amputation of the limb; and as there could be no doubt that in both cases they were produced in the same manner, there was no longer any reason to suspect that sympathetic ganglia in the trunk might have had any share in their development in the former instance. Yet the circumstance above mentioned, that in the amputated limb the tendency to constriction usually affected a considerable tract of the vessel, and sometimes its entire length, to nearly the same degree, or in other words, that the muscular fibre-cells of the circular coat of the artery still contracted in concert with each other, seemed to imply the operation of a coordinating nervous apparatus contained in the limb. It appears probable that the means by which these concerted movements are induced are nerve-cells disseminated through the limb, in the same manner as MEISSNER has lately shown to be the case in the mammalian intestine*. The intestines also present a parallel to the arteries, in the fact that contractions of their unstriped muscular fibres result from arrest of the circulation in them; and I have lately shown† that these movements are not due to any influence exerted directly upon the contractile tissue, but that the intestinal nerves are essential to their production. Thus we have support from analogy for the view that the muscular contractions which occur under similar circumstances in the arteries are induced by nervous agency.

The fact that the contraction produced in an artery of the frog's web by pressure upon a particular point affects a considerable extent of the vessel, instead of being limited to the spot irritated, is also an argument for the existence of a local coordinating apparatus; for I find that this occurrence continues to take place in an amputated limb. The observation was made on the 4th of August, 1858. One of the hind legs of a frog having been removed after a ligature had been passed round the thigh so as to prevent escape of the blood, pressure was made with a fine but blunt instrument over a particular point in the course of a large artery, whose calibre had previously been accurately determined by micrometer. The contractions which resulted affected the immediately adjacent parts of the vessel to an extreme degree; the effect, however, was not limited to these, but gradually shaded off in both directions; and even at a considerable distance, where by ordinary observation no change might have been detected, the micrometer showed a diminution from 6° to 5°‡, occurring immediately upon the irritation and subsiding soon after. Similar results were obtained on repetition of the experiment.

* HENLE and PFEUFER's 'Zeitschrift,' 2nd series, vol. viii. 1857.

† Vide "Preliminary Account of an Inquiry into the Functions of the Visceral Nerves, &c.," Proceedings of the Royal Society, vol. ix. No. 32. p. 370.

‡ These degrees have a different value from those mentioned in other parts of this paper, a different micrometer having been employed.

From the analogy of the intestinal and cardiac movements*, it is probable that the local coordinating apparatus for the arteries comes into play in all cases of arterial contraction in the living animal, and is the medium through which the nerves which arise from the cord act upon the vessels. But it is very important to bear in mind that it is, under ordinary circumstances, in entire subjection to the spinal system, and only acts independently under special conditions of local irritation.

It remained as yet undecided whether the nervous centre for the arteries contained in the cerebro-spinal axis were extensively diffused or limited to some particular region of it. The experiments hitherto related had revealed nothing absolutely irreconcileable with the hypothesis of a spot about the middle of the cord being the special regulator of the contractions of the vessels; a view indicated, though by no means proved, as regards the arteries of the face and fore-limbs in Mammalia, by the observations of WALLER and BUDGE and of SCHIFF, alluded to at the commencement of this paper. It appeared probable that this point might be readily determined by removing the middle third of the cord, and ascertaining whether or not the arteries still retained their contractility†. Accordingly, on the 26th of August, 1857, having selected for measurement an artery in one of the webs of a frog, I divided the cord transversely at the distance of a quarter of its length from the posterior end, at $11^h\ 7^m$ A.M. During the next half-hour the diameter of the vessel was observed varying frequently from $\frac{1}{2}°$ to $1\frac{1}{2}°$. At $11^h\ 34^m$ the cord was again cut across opposite the middle of the scapulæ, *i. e.* at a distance of a little more than a quarter of its length from the occiput. After this operation the artery was observed for about a quarter of an hour varying occasionally in calibre between 1° and 2°. At $11^h\ 53^m$ the portion of cord intervening between the two transverse incisions, and measuring very nearly half its entire length, was removed, immediately after which the artery measured $1\frac{1}{2}°$. At $11^h\ 55^m$ its diameter was 1°, the heart meanwhile continuing in good action, and twelve minutes later the vessel was again seen to change in calibre from 1° to $1\frac{1}{2}°$ and back again to 1°. The heart's action afterwards became very feeble, and the parts of the nervous centres concerned in regulating the arterial calibre appeared also to be failing in their functions, the vessel varying very slightly, and gradually increasing in diameter, till towards 1^h P.M. its measurements were from 2° to $2\frac{1}{4}°$. At $1^h\ 1^m$ the posterior end of the cord was removed, immediately after which the diameter of the artery was above $2\frac{1}{4}°$, or larger than ever seen before; at $1^h\ 4^m$ it was near $2\frac{1}{3}°$, and continued so at $1^h\ 10^m$. Soon after this the circulation ceased entirely.

In this case, notwithstanding the removal of the two middle quarters of the cord, the arteries were observed moderate in size and varying in calibre at a time when the heart was acting well. Hence it was evident that the middle portions of the cord are not

* See "Preliminary Account, &c.," before referred to.

† In the original manuscript I was obliged to express my regret that time had not yet permitted me to carry out this idea. The dates in the text indicate that it has been done since the paper was read.

essential to the regulation of the arterial contractions in the feet. The following experiment confirmed this important conclusion, and also furnished additional information.

On the 20th of October, a large frog having been placed under chloroform, the cord was divided transversely at the distance of about one-fifth of its length from the posterior extremity. At 4^h 20^m P.M., just after the operation, an artery in the right foot measured $2\frac{1}{3}°$, the vessels appearing generally of pretty full size, and the flow of blood rapid through the web. At 4^h 25^m the cord was again cut across a little behind the mid-scapulæ, at a distance from the occiput of somewhat more than a quarter of the length of the cord. At 4^h 33^m the diameter of the vessel was $1\frac{1}{3}°$. At 4^h 40^m the portion of cord included between the incisions was removed, without any interference with either the anterior or posterior segment. It was observed that a large branch for the hind legs, furnished by the middle segment, had to be divided during its removal, and immediately after the operation the artery measured $2\frac{1}{3}°$, and the flow of blood in the web was much more rapid than before. At 4^h 45^m the artery had contracted to 2°, at 5^h 7^m it measured short of 2°, and a minute later was again 2°. At 5^h 11^m I introduced a fine needle into the anterior segment of the cord with the effect of causing convulsive movements of the fore legs, but no change whatever in the calibre of the artery in the hind leg. I afterwards repeated this experiment twice, and the last time carried the needle on into the brain, and stirred it up thoroughly, but no effect was produced upon the vessel. At 5^h 23^m the whole brain was removed, together with the anterior segment of the cord; the artery, however, still continued to measure 2°. At this time the circulation, though somewhat enfeebled, was still pretty good. At 5^h 53^m a complicated operation was performed upon the left thigh, to which I need not allude further than to mention, that it no doubt involved exposure of the other foot to a higher temperature than before, in consequence of the vicinity of my hands, and this was probably the cause of the dilatation of the arteries observed immediately afterwards, that which had been previously measured being now $2\frac{2}{3}°$. Five hours later the artery was again 2°, but the heart's action was excessively languid. Next morning the circulation was going on steadily, though somewhat slowly, the heart having obviously recovered to some extent during the night. The arteries were larger than ever seen before; the calibre of that above noted being $3\frac{1}{4}$, and there were a good many blood-corpuscles adhering to the walls of the vessels. It is probable that the small posterior segment of the cord had become impaired in its powers, but that it was still acting to some extent was evident from the circumstance that after its removal at 10^h 56^m A.M., the vessel was found increased to 4°, and in consequence of the arterial dilatation, the stagnation of the red corpuscles, which existed in several parts of the webs, was almost entirely dispelled, although the action of the heart did not appear to have been changed. During the next half-hour the artery was measured four times, and was in every instance found to be still 4° in diameter. I may mention that I measured the posterior segment of the cord immediately after its removal, and found its length to be one-sixth of that of the whole cord; it was in fact little more

than the tip of it; but allowing for a certain amount of contraction, it may be reckoned as one-fifth.

This case shows that the extremity of the cord acts as a nervous centre for the arteries. But the experiment of the 2nd of June proved that after the removal of the greater part of the posterior half of the cord, the vessels still remained under the control of the nervous system*. Hence it is clear that the nervous centre for the arteries is not confined to any limited region of the cord.

This experiment also indicates, in a very striking manner, how small a piece of the cord will suffice to regulate the calibre of the arteries, and how little effect may be produced, even in the first instance, by the removal of a large portion which also possesses that function. For it was shown, by the absence of contraction in the vessels when the anterior segment was irritated, and still more conclusively by the absence of dilatation when the anterior segment and the brain were removed, that the posterior segment was the only part capable of acting on the arteries after the removal of the middle segment; or, in other words, that this operation deprived the arteries of the influence of the whole cerebro-spinal axis, except the posterior fifth of the cord. Yet, although the heart was acting powerfully at the time, the dilatation produced by this procedure was only moderate in amount, and very transient. Hence it follows that the mere fact of the speedy return of the arteries to their former state of contraction, after removal of an anterior portion of the cerebro-spinal axis, as seen in the experiment of April 16th, 1857†, is no ground whatever for believing that such a portion does not act as a nervous centre for the arteries. This being clearly understood, the invariable occurrence of contraction, when the posterior part of the brain or the anterior half of the cord was irritated, in the experiments of April 14th and 16th, 1857‡, must be regarded as strong presumptive evidence, if not absolute proof, that they as well as the posterior half of the cord preside over the arterial contractions in the feet, although, as shown at page 615, they appear to exert their influence only through those roots of nerves which take origin from the posterior regions of the cord. On the other hand, the cerebral hemispheres seem to take no part in this function, so far at least as it is safe to draw any inference from the negative evidence derived from a single experiment performed upon them, viz. that mentioned at page 610.

The fact that the removal of a large portion of the cord is followed by only temporary dilatation of the arteries, provided that a part remains which furnishes roots of nerves for the posterior extremities, is in harmony with the transient effects which were seen to be produced upon the vessels by partial division of the roots of the nerves within the spinal canal in the experiments of April 8th and 11th, 1857§. In both these cases the arteries of the webs appeared to recover their contractile power completely, although the leg remained nearly, if not entirely, paralysed; which seems to indicate that a few fibres of the nerves for the blood-vessels of a part can supply the place of the rest more perfectly than is the case with the ordinary nerves of sensation and motion. This peculiarity of

* Vide page 616. † Vide page 613. ‡ Vide pp. 611, 613. § Vide pp. 609, 610.

the "vaso-motor" nerves is more strikingly illustrated by the first experiment mentioned in this paper*, in which it may be remembered that the arteries of the webs completely recovered their usual powers of varying their calibre within half an hour after division of the sciatic, although this is an operation which abolishes for days at least all sensation and voluntary motion in the leg. I have since seen yet more remarkable instances of the same thing. On the 10th of October, 1857, with the view of investigating the nature of the control exercised by the nervous system over the actions of the pigment-cells†, I divided all the soft parts in the middle of the thigh of a frog, except the main artery and vein. The first effect upon the arteries was full dilatation; but about twenty-four hours later they were again of moderate size, while the circulation was still active. After the death of the animal, I examined with the microscope the coats of the artery and vein, and also the periosteum, together with a very slight amount of muscular tissue adhering to it, but could detect no nerves in any of them, although from the method of examination I could hardly have missed branches containing more than very few nerve-tubes. Comparing the result in this case with the permanent dilatation which always occurred after removal of the spinal cord, so long as the circulation continued active, it was evident that the slender filaments contained in the coats of the vessels, or possibly in the bone, had served as an efficient means of communication between the cerebro-spinal axis and the arteries of the foot.

On the 13th of the same month I repeated the experiment upon another frog, operating in this case upon both thighs. In the first place, I divided thoroughly all the soft parts except the artery, vein and nerve, the circulation remaining unaffected. The nerves were then successively cut, full dilatation of the arteries and rapid flow through the capillaries being the immediate result. An hour and a half later, however, the flow was observed to be less rapid, no doubt in consequence of slight contraction of the arteries, one of which, in the left foot, measured 3° by micrometer, and after sixteen hours more they were both moderate and variable in calibre in both feet; that in the left limb before noted now changing between $1\frac{1}{2}$° and 2°, and a principal artery in the right foot between 1° and $1\frac{1}{2}$°. The circulation meanwhile continued active, and remained so more than twelve hours longer; from which circumstance, as well as from the normal appearance of the contractions, it was evident that the arteries were still under the control of the cord; and I may add, that in another animal in which the same operation was performed upon the thigh after removal of the brain and cord, the arteries remained of full size and without variation for thirty-four hours, after which circulation ceased.

From these facts it appears that there exists a very remarkable provision for ensuring the proper regulation of the arterial calibre in a part in spite of almost complete divi-

* Vide page 609.

† Further information regarding this experiment, as respects the pigmentary system, will be found in the next paper in these Transactions.

sion of the nerves connecting the vessels with the nervous centre which presides over their contractions. It has been shown by recent discovery that sensation and voluntary motion are abolished in parts whose nerves have been divided, until repair has been effected by a process of fresh formation of the nerve-fibres. But the control of the flow of the nutrient fluid is not allowed to be interrupted in this manner, but continues to be exercised more or less perfectly, notwithstanding nearly absolute severance of nervous connexion.

Allusion has been more than once made to the circumstance that arteries do not dilate so fully when the heart is very feeble as when it is in powerful action. This was strikingly illustrated in the case of the frog which was the subject of operation on April 16, 1857. Immediately after the experiments recorded at page 614, the heart having ceased to cause movement of blood in the web, I induced complete constriction of the arteries by irritating with a needle the posterior part of the cord, and then thoroughly cleared the spinal canal of its contents. The artery under special observation did not, however, become dilated to a greater diameter than $1\frac{1}{2}°$, although during the earlier experiments, when the heart was acting vigorously, it had been observed to attain sometimes a calibre of 3°. The heart never recovered its power, and the vessel maintained this medium width as long as I continued to examine the animal, namely, three hours.

From this and other similar observations, I infer that full dilatation of the arteries is a merely passive phenomenon as respects the parietes of the vessels. Contraction is effected by the muscular fibre-cells of their circular coat, on the relaxation of which the elasticity of the arteries tends to make them expand to a certain degree, beyond which they do not dilate, except in so far as they are distended by the blood.

It was observed by WHARTON JONES*, that section of the sciatic nerve in the thigh of a frog was followed after a time by œdema of the limb and exfoliation of the epidermis. If this were dependent on the dilatation of the arteries produced by the division of the nerve, the fact would have a very important bearing upon the cause of inflammatory effusion. I find, however, that neither œdema nor exfoliation results from permanent full dilatation produced by operations upon the cord or the roots of the spinal nerves; while, on the contrary, both took place in the case of division of the sciatic, given in the early part of this paper, in which it will be remembered that the arteries recovered their contractility completely within half an hour, and presented, during the next twenty-four hours, precisely similar appearances with those in the other foot. Hence it is evident that the phenomena in question are not due to vascular relaxation, but to some other circumstances attending the operation performed upon the thigh.

It remains to be added, that, in a healthy state of the web, no change in the properties of the blood was ever observed to accompany the constriction of the arteries on irritation of the cord, or the dilatation which followed the destruction of the nervous

* Medico-Chir. Trans. *loc. cit.*

centre. The exsanguine condition of the web in the former case, and the turgid state of the vessels in the latter, were simply the effects of the variations of calibre in the arteries, the blood flowing more freely in proportion to their width*.

To sum up the principal results of this inquiry, it appears—

1st. That, of the nervous centres usually recognised, the cerebro-spinal axis is the only part which regulates the contractions of the arteries of the webs; this function being apparently exercised by the whole length of the cord and the posterior part of the brain, operating through fibres which arise from the same region of the cord as do those through which sensation and motion are effected in the hind legs.

2nd. That there exists within the limb some means, probably ganglionic, by virtue of which the fibre-cells of the circular coat of the arteries may contract in concert with each other, independently of any ganglia contained in the trunk.

And 3rd, that the local coordinating apparatus, though capable of independent action in special conditions of direct irritation, is, under ordinary circumstances, in strict subordination to the spinal system; while a remarkable provision exists for the maintenance of this control, notwithstanding almost complete severance of nervous connexion between the cord and the limb.

* The subject of the effect of variations in the calibre of the arteries upon the flow through the capillaries, will be found fully discussed in the paper "On the Early Stages of Inflammation," published in this volume.

XXX. *On the Cutaneous Pigmentary System of the Frog.* By JOSEPH LISTER, *Esq., F.R.C.S. Eng. and Edin., Assistant Surgeon to the Royal Infirmary, Edinburgh, Communicated by Dr.* SHARPEY, *Sec. R.S.*

Received June 18,—Read June 18, 1857*.

THE fact that the skin of the frog is capable of varying in colour, has been for some years known to German naturalists. The first account of the mechanism by which these changes are effected, appears to have been given by Professor BRÜCKE, of Vienna, in 1852†, and the subject has since been very carefully investigated by Dr. VON WITTICH of Königsberg‡, and Dr. E. HARLESS of Munich§. All these observers describe the dark pigment as contained in stellate cells, each composed of a central part or body and several tubular offsets, which, subdividing minutely and anastomosing freely with one another and also with those of neighbouring cells, constitute a delicate network in the substance of the true skin. They describe the dark contents as sometimes concentrated in the bodies of the cells, at other times diffused throughout the branching processes, the skin of the creature being pale in the former case and dark in the latter. In the tree-frog the change from a dark to a pale state of the body generally was induced by bringing the creature into a bright light, by psychical excitement (as was supposed¶), or by galvanizing the spinal cord; and a similar effect was produced on a particular portion of the surface by irritating it mechanically, or with oil of turpentine, or by galvanism applied either directly to the part, or through branches of nerves leading to it. After the source of irritation was removed, the skin returned somewhat slowly to its former colour; and VON WITTICH noticed that when the paleness produced by direct irritation had passed off, the tint became deeper in the irritated spot than elsewhere. The esculent frog exhibited similar phenomena, but was less sensitive. The concentrated state of the pigment is attributed by all the observers above named to contraction of the cells, while the diffused condition is supposed due to their relaxation. The con-

* During the time that has elapsed between the reading of this paper and its publication, several new observations have been made, which it has been thought best to introduce into the text, distinguished by date or foot-note from the matter of the original manuscript.

† Untersuchungen über den Farbenwechsel des Africanischen Chamaeleons, iv. Band der mathemat. naturwissenshaftl. Classe der Kaiserl. Acad. d. Wissenschft. Wien. This paper I have not yet had an opportunity of consulting.

‡ MÜLLER's Archiv, 1854.

§ Zeitschrift für Wissenschaftliche Zoologie, vol. v. 1854.

¶ This rests on the authority of VON WITTICH; but, for anything stated to the contrary in his paper, the effects ascribed to psychical excitement may have been connected with the efforts of the creature in struggling, independently of any emotional change.

tents of the cells are described as dark granules suspended in a fluid; and both VON WITTICH and HARLESS have distinctly seen the granules rolling along in the offsets during the process of concentration. All the authorities agree in the opinion that the fluid and granules move together from one part of the cell to another, the offsets being supposed empty of both when the pigment is accumulated in the body of the cell*.

In some respects the above description agrees with my own experience of the common frog of this country (*Rana temporaria*). I find that this well-known animal exhibits changes of hue almost as great as those of the chameleon, every specimen being capable of varying from a very pale to a very dark colour, the former being generally greenish yellow, but in some varieties reddish; and the latter brownish black, or sometimes coal black; while between these extremes any intermediate shade may be assumed. The depth of tint is generally proportioned to that of surrounding objects: thus a frog caught in a recess in a black rock was itself almost black; but after it had been kept for about an hour on white flagstones in the sun, was found to be dusky yellow, with dark spots here and there. It was then placed again in the hollow of the rock, and in a quarter of an hour had resumed its former darkness. These effects are independent of changes of temperature; for similar results may be obtained by placing a frog alternately in a vessel from which luminous rays are excluded, and in a white earthen jar covered with glass, in the same situation. Different examples, however, differ much in their sensitiveness to light. A violent struggle on the part of the animal is often followed by a speedy alteration from a dark to a pale state of the skin. It seems very doubtful whether psychical excitement has anything to do with this occurrence, any more than with the arterial contraction which invariably takes place under such circumstances. Neither oil of turpentine nor galvanism, when applied to the integument, produces, so far as I have seen, any effect upon its colour; our species being little influenced in this respect by direct irritation. I have however frequently observed, after forcibly pinching a dark web, that a pale ring, about $\frac{1}{16}$th of an inch in breadth, has formed around the area so treated; but this was very slow in appearing, being first noticed from half an hour to an hour after the pinch was given.

The webs of the hind feet, examined under a low power of the microscope, exhibit differences in the distribution of the dark pigment† according to the tint of the skin,

* From the way in which VON WITTICH alludes to BRÜCKE's description, it is clear that the latter supposed the cells to be contractile. VON WITTICH himself in his first paper speaks of the movement of the pigment induced by galvanism as "satisfactorily" showing "that the stellate pigment-cells are contractile." In his second paper (vide MÜLLER's Archiv, 1854, p. 263), he expresses some doubt regarding the contractility of the *cell-wall*, but clearly speaks of the contents (fluid and granules) as moving together. HARLESS, after describing "the rolling of the pigment-molecules towards the centre of the cell," goes on to say, "that this rolling may be possible, there must be a fluid in the cells and offsets, *to which* the molecules owe their movement." He takes it for granted that the movement of the fluid must be due to some contractile agency, and as he finds no apparatus of this nature around the cells, and as the unstriped muscular fibres of the skin have no special relation to them, he infers that the cell-wall is itself contractile.

† Other kinds of pigment are also present in the skin of the common frog, generally of yellow colour,

such as will be understood by referring to Plate XLVII., where fig. 1 is from a dark portion of web, and fig. 2 from a pale part in the same animal. In fig. 2 the colouring matter is seen to be collected in black spots of irregular angular shape. This, however, is not the state which exists when the colour is palest, for then the masses of pigment are in the form of round dots, as in the part to the right in fig. 1, Plate XLVIII. Neither does fig. 1 of Plate XLVII. give the condition met with when the skin is darkest, in which case all that meets the eye on superficial observation is a reticular appearance, such as is represented in the stripe down the middle of fig. 1, Plate XLVIII., and in the lower part of fig. 2 in the same Plate. When the colour of the integument is about medium, the pigment is disposed in a truly stellate manner, as on the left side of fig. 1, Plate XLVIII. It may be convenient for the purposes of description, to designate these various states as respectively the dotted, angular, stellate and reticular conditions of the pigment.

When a higher magnifying power is applied in an extremely dark state of the skin, the chromatophorous cells, for such they seem to be, appear as depicted in Plate XLVII. fig. 3, where two of them are given, along with an adjacent capillary distended with blood-corpuscles. Each cell consists of a somewhat flattened central part with several irregular offsets, of considerable diameter near the central part, but speedily breaking up into small branches. The ultimate ramifications, some of which are of extreme minuteness, anastomose freely with one another and with those of neighbouring cells, constituting a very delicate and close-meshed network, which pervades the whole thickness of the true skin, and especially follows the course of the blood-vessels, entering into the composition of the cellular coat of the arteries and veins, and twining about the capillaries in a very remarkable manner. The walls of these cells and of their tubular offsets appear to be extremely delicate, and some attempts which I have made to isolate them from surrounding tissues have barely served to demonstrate their existence. The cells vary considerably in dimensions according to the size of the animal; thus, those in figs. 8, 9 and 10, which are from young frogs, though magnified 500 diameters, show in the drawing even smaller than those in fig. 3, magnified only 250 times, the latter being from a full-grown specimen. In an average full-sized cell of a large frog, the middle portion was found to measure $\frac{1}{350}$th of an inch in length by $\frac{1}{670}$th of an inch in breadth, and $\frac{1}{1500}$th of an inch in thickness. The last-named dimension was obtained by carrying the focus of an object-glass of high power, from the most superficial to the deepest part by the screw for giving slow motion, and reading off on its graduated circle

but sometimes red. My attention has not been much directed to these, but I have noticed that they are contained in receptacles of the same general form and structure as those which hold dark pigment; and on one occasion, since the reading of the paper, I observed the colouring matter disposed in a stellate manner with complex ramifications in one part of a web, and in another part collected into round spots; implying that these cells possess the functions of concentration and diffusion of the pigment. They do not, however, always act in harmony with the dark cells; and it is probably through their agency that changes in tint, such as I have seen to occur in one and the same frog, independent of mere lightness and darkness of shade, are produced.

the number of divisions traversed, these having a known proportion to the depth measured. Opportunities for testing the correctness of this measurement were presented by other cells which lay edgewise, so that their thickness could be observed directly.

Perhaps the strongest argument in favour of the cellular nature of these receptacles of colouring matter is afforded by the universal presence of a nucleus in the central cavity of each. In large frogs it is often difficult or impossible to discover clear evidence of it, but in small ones, in which the web is much thinner and its constituent parts therefore capable of clearer definition with the microscope, it can be quite distinctly seen in the reticular condition of the pigment. Its form and relations may be gathered from figs 8, 9 and 10. In 8 and 10 the bodies of the cells are viewed on the flat, and the nucleus appears as an oval colourless body, about $\frac{1}{3500}$th of an inch long by $\frac{1}{3300}$th of an inch broad. In fig. 9 the body of the cell is seen edgewise applied to the wall of a capillary blood-vessel, which is embraced by its processes. The thickness of the nucleus is thus displayed, and is shown to be equal to that of the cell in which it lies, which in fact it causes to bulge slightly, and also nearly as great as the breadth of the nucleus in figs. 8 and 10. In the cell of fig. 10, the thickness of the nucleus, measured in the manner above described, was found about equal to its breadth. The nucleus in fig. 8 is not centrally placed in the body of the cell, and I have in some other cases seen it still more excentric*.

The contents of these cells are very minute dark granules or molecules suspended in a colourless fluid, in which I have often seen them moving freely: when in considerable mass they produce a jet-black appearance, but exhibit a brown tint when present only in small quantity.

When the skin of the animal is very pale, the colouring matter is all accumulated in the central parts of the cells. With regard to the method in which this change is effected, I am compelled to differ altogether from the before-mentioned authorities, who suppose that the granules and fluid are together forced by contraction from the processes into the bodies of the cells. They seem to take it for granted that the depth of tint of any one part of a cell depends simply upon the bulk of the contents situated there, and the consequent thickness of the coloured medium through which the light passes before reaching the eye. This, however, is by no means the case, as may be seen by referring again to Plate XLVII. fig. 3. The pigment is there represented fully diffused through the ramifications of the offsets, and some of the smallest of these are darker than the bodies of the cells and the adjoining broad parts of the processes; yet the former are far from being thicker than the latter: on the contrary, some of the branches, though conspicuous for their blackness, appear but as delicate lines which can be seen only at one focus when a glass of very high power is employed; while the bodies of the cells, as above mentioned, possess considerable thickness, and the processes are

* The precise relations and dimensions of the nucleus have been ascertained subsequently to the reading of the paper.

not flat, but subcylindrical. But the differences in tint are sufficiently accounted for by the circumstance that in the dark branches the colouring particles are closely packed together, whereas in the bodies of the cells and the paler parts of the offsets, the individual granules are separated from one another by considerable colourless intervals. Hence it is clear that the degree of darkness of any part of a cell does not depend so much on the bulk of its contents in the aggregate, as on the proportion which the pigment molecules in it bear to the fluid in which they are suspended.

If the whole contents of the processes were forced into the central parts during concentration of the pigment, and driven back again during diffusion, the bodies of the cells would be subject to great variations in capacity, becoming turgid in concentration and collapsed in diffusion; and the bulk of the central coloured mass would be great in the former case, but small in the latter. The very reverse, however, really takes place. Fig. 6 represents the appearance of the pigment in a concentrated condition, in one of the same cells which in fig. 3 show it in full diffusion. During the time in which this change took place, the adjacent capillary had shrunk to about half its former size, but it will be recognised by its general form, and will indicate which of the two cells is that under consideration. Both the figures were drawn on the same scale with the camera lucida*, so that accuracy of proportion is ensured. The circular black mass into which the colouring matter is now all collected, measures less across than either the length or breadth of the body of the cell in the diffused state of the pigment. Further, the mass is not spherical, but of flattened form, and its thickness is only about that of the central part of the cell in diffusion. This we know from the appearances presented by the spots of concentrated pigment in other cells seen edgewise, as is the case with some in fig. 7, which represents the outline of the wall of a large blood-vessel, and the pigment contained in its external coat in nearly complete concentration. Hence it appears that all the pigment-granules contained in the body of the cell and the minutely ramifying processes in the diffused state, have been brought together into a space considerably less than was then occupied by the pale contents of the body of the cell alone. The coloured particles have been concentrated into a dense disciform mass, but the fluid in which they were suspended has been left behind.

Fig. 4 shows the pigment in the same cells as fig. 3 in an intermediate stage, in which the process of concentration is about half accomplished; the upper one being in the condition which would appear stellate under a low magnifying power. The greater part of the pigment is collected in the bodies of the cells, especially towards their central parts: in the middle of each dark mass, however, is a pale spot, doubtless due to the circumstance of the granules not having yet insinuated themselves between the cell-wall and the nucleus, which, as shown above, probably lies in contact with it. This appearance of pale central points was very general in the web at the time when fig. 4 was drawn, but gradually disappeared as the aggregation of the pigment-molecules proceeded, and does

* All the drawings in the two Plates which accompany this paper were made with the assistance of this very valuable instrument.

not exist in fig. 5, which represents the lower of the two cells in a more advanced state of concentration. The remote branches of the processes were then for the most part invisible, and those which did appear were generally pale, instead of dark, as they had been during full diffusion. This difference does not depend on contraction of the branches, but on the granules being absent from them, or sparsely scattered instead of closely packed; and I have often ascertained from some granules remaining widely separated in a process, that it was of large calibre, though, without careful searching, it would have seemed invisible. Even in fig. 6 concentration is not represented absolutely perfect; for a few molecules are to be observed near the black mass in the more circumferential parts of the body of the cell. The extreme delicacy of the cell-wall makes it very difficult to trace it among the surrounding tissues, and I have not attempted to give it in these figures, which, it must be clearly borne in mind, represent only the colouring matter. The external parts of the body of the cell and the principal processes may, however, be sometimes discovered, though perfectly colourless in consequence of concentration: they are then found to be of the usual dimensions met with in full diffusion, showing that they are still full of fluid though destitute of granules. In fact the only change of form to which the cells appear liable, is a slight bulging of the central part at the seat of the black mass in the concentrated state, which I have detected in some cases by camera lucida sketching, and which is consistent with the separation of the cell-wall from the nucleus, implied by the ultimate disappearance of the central pale points of fig. 4.

The movement of the granules towards the centres of the cells may be seen without any great difficulty. The death of a healthy frog is always followed by complete concentration of the pigment for a time, however much diffused it may have previously been, and the process taking place gradually, its progress can be observed. If a frog with the skin dark, and the pigment therefore diffused, be killed and the web examined soon with a good glass of high power, the granules may be seen distinctly moving along the offsets of each cell to join the dark mass which is becoming accumulated in the central part. If the process is going on languidly, the individual molecules advance slowly with slightly dancing movements, indicating that they are free in the fluid and not confined in any way to the cell-wall. If concentration is taking place more speedily, the granules rush along so quickly that no time is allowed for observing their molecular movements, and often their motion is so rapid as to elude the eye altogether. In one instance a large-sized offset, which at first contained abundance of pigment, became gradually cleared in this way of its colouring matter without any change in its dimensions, till it was almost invisible on account of the very small number of molecules remaining in it.

It is thus a matter of direct observation, that the pigment-granules move along into the bodies of the cells during concentration, and leave colourless fluid behind them in the processes. It is clear that their motion cannot be explained by currents in the fluid; for streams proceeding towards the centre of a cell would necessarily be accompanied by a returning flow in the opposite direction, which would carry the pigment with

it unless the molecules had a special tendency towards the centre. The circular form assumed by the mass of pigment when concentration is complete, is strongly suggestive of a central attractive force acting on the granules. The occurrence of the central pale points, which are represented in fig. 4, showing that the nucleus was there in the middle of the concentrating pigment, led me at first to suppose that this body was the attractive agent*. I afterwards took pains to ascertain whether the nucleus always has this relation to the mass, and found that such is not the case. On the 22nd of October, 1857, I watched three adjacent cells during the process of *post mortem* concentration; in two of them the nucleus ultimately projected by about a quarter of its length at one side from the black spot, while in the other cell the aggregated molecules covered only one-third of the nucleus, so that *no part* of that body lay in the middle of the mass. The point to which the granules appear to have a special tendency is the middle of the body of the cell, which seems always to correspond with the centre of the disc of molecules, whereas the nucleus is often excentrically placed in the cell.

The diffusion of the molecules is not merely a passive result of the cessation of concentration, as has been hitherto supposed. In watching closely the occurrence of the phenomenon, I have seen† the granules start off suddenly from the central mass, with a velocity which implied that they were under the influence of forces very different from those which cause molecular movements in them when shed from their containing cells. That the process requires the vital forces of the cells to be in full operation, is also proved by the fact, that any agency, such as a galvanic shock, which temporarily paralyses their functions, arrests diffusion as well as concentration; whereas, if the former were merely passive, it would take place as soon as the concentrating power was set at rest‡.

I have already pointed out the sparsely scattered state of the granules in the central receptacles, compared with their accumulation in the branches of the offsets, in the fully diffused state shown in fig. 3. This contrast is sometimes much more striking, so that the bodies of the cells are almost colourless, and require some experience with the tissue in order to detect them. This indicates a special tendency on the part of the granules to leave the middle of the cell. Yet to however great a degree diffusion be carried, there always remain some molecules in the body of the cell uniformly distributed throughout its thickness and not attached to the parietes, as they would have been had their dispersion been caused by attraction on the part of the cell-wall. This disposition of the granules, which obtains even in the immediate vicinity of the nucleus, appears also distinct evidence against the operation of a central repulsive force; for this would render the body and the adjoining parts of the processes as clear of pigment as the remote branches are made in concentration. The hypothesis which would seem most

* This was the view expressed in the paper as it was read.

† This observation was made after the reading of the paper.

‡ For further information regarding the effects of various agents on the functions of the pigment-cells, see the next paper in this volume.

consistent with the appearances described, is that of a mutual repulsion on the part of the pigment-granules, induced by some agency strongest at the centre of the cell and feeble in the remotest branches of the offsets.

On the 27th of October, 1857, I was observing a cell in which *post mortem* concentration had occurred, the pigment being in the angular condition. At one of the angles movements of the granules were going on, of which I will content myself with giving two examples. At one time a number of molecules started off together with great rapidity from the black mass, but stopped after having proceeded a certain distance; some of them remaining in their new position, while others returned at various rates towards the centre. At another time an individual granule moved slowly away for a little space, and then came back by a circuitous route to a different part of the mass from that which it had left. What I then saw has led me to believe that the movements of the pigment-molecules are of a complex character that will perhaps never be fully explained. In the mean time it is clear that concentration and diffusion are both active vital functions, and that both imply peculiar relations of the centre of each cell to the pigment-molecules, as distinguished from the fluid in which they are suspended.

These conclusions invest the pigmentary changes with deep physiological interest. In the movements of the granules towards and from the centres of their containing cells, we now have ocular demonstration that a particular kind of material may have impressed upon it by vital action, independently of muscular contraction or ciliary motion, tendencies to rush energetically to or from certain fixed points in the tissues, through distances equal to nearly twice the thickness of a villus of the human intestine, and several times greater than the average breadth of a human capillary interspace. Whether we be able to explain the means by which such results are accomplished or not, it is obvious that forces of similar powers and range of operation, if suitably modified according to the circumstances of each case, would be more than adequate to cause the passage of particles of fat from the cavity of the intestine into the central lacteals of the villi, or the transit of the material required for a particular secretion or act of nutrition out of a capillary into a neighbouring gland cell or other portion of tissue; and, again, for the discharge of an elaborated product of secretion into a duct, or the return of waste matter into the blood-vessels or lymphatics. We thus obtain a basis of fact for what has hitherto been merely conjectural, in the explanation of the processes of absorption, secretion and nutrition generally.

The functions of the pigment-cells are under the control of the nervous system *, as is evident from the effects produced on the colour of the skin by a struggle on the part of the animal.

Much attention has been devoted by von Wittich to the inquiry, by what ganglionic centres this control is exercised. He found that division of the sciatic nerve in the

* The part of the paper devoted to this branch of the subject has been entirely rewritten; and the dates in the text imply that most of the observations with reference to it have been made since the reading of the manuscript before the Society.

thigh, or of cutaneous branches in the dorsal region, did not prevent the parts of the skin supplied by them from varying in colour along with the rest of the body under the influence of light; and, supposing that in such operations all connexion was severed between the portions of integument concerned and the central organs of the nervous system, he inferred that the pigmentary changes induced by light were effected independently of either the cerebro-spinal axis or the usually recognised sympathetic ganglia. He nevertheless regarded such variations as probably reflex in their nature, and attributed them to a peripheral ganglionic apparatus in the skin itself; and this opinion appeared confirmed by the circumstance that direct irritation operated in the same manner upon the colour of a detached piece of integument as upon that of the living animal. At the same time, as he observed paleness of tint to result from irritation of the cord, or of the nerves distributed to a particular part of the surface, he concluded that the spinal system was also capable of acting on the pigment-cells, and so accounted for the supposed influence of psychical excitement upon the tint of the skin. Thus, according to his view, the cutaneous pigmentary system was circumstanced like the heart or intestines, which, though possessing the faculty of independent action by virtue of their intrinsic ganglia, may also have their movements affected by mental emotion*.

In the course of some experiments performed in April 1857, with reference to the influence exerted by the cord upon the calibre of the arteries, I noticed on two occasions that partial division of the roots of the nerves for one of the hind legs within the spinal canal was immediately followed by increased paleness of the limb, of transient character, after which the leg assumed precisely the same colour as the other, this result being in accordance with VON WITTICH's description. But I further observed in two cases in which such operations had been performed, that when a considerable time had elapsed, viz. nine hours in one instance and two days in the other, the limb whose nerves had been cut was decidedly darker than the rest of the body. Similar results were once obtained from the division of the sciatic nerve in the thigh. When the operation was performed, viz. at $4^h\ 30^m$ P.M. on the 4th of April, 1857, the pigment was in the stellate condition in the webs, the tint of the skin being moderately dark; and this state of things continued unchanged in both limbs for the next six hours. On the following day, however, the leg operated on was seen to be very dark, and the pigment in its webs was reticular; while in the rest of the body the colour remained as before, and the pigment was still stellate. This striking contrast continued unaltered for two days, when it was destroyed by the body generally assuming the darkest possible tint.

The diffusion of the pigment in consequence of division of nerves appeared to be the counterpart of the concentration produced by their irritation, and it seemed probable that the want of constancy in the results in the former case was caused, like the variable amount and duration of arterial dilatation after such operations†, by the place of the divided trunks being supplied by other branches; and that, if the nerves of a limb were all completely severed, diffusion would necessarily take place. With the view of testing

* Vide MÜLLER's Archiv, *loc. cit.* p. 56.

† See page 610.

the truth of this idea, the following experiment was performed. In the afternoon of the 10th of October 1857 I divided in a pale frog all the soft parts in the middle of the right thigh, except the femoral artery and vein and the sciatic nerve; and late in the evening, having ascertained that the circulation was going on freely in the webs, I cut the nerve also, no effect having been hitherto produced upon the colour of the limb. Next morning the body generally was still pale, but the right leg was black from the wound downwards. The same remarkable appearance continued till the evening, when circulation ceased in the limb. On the 13th I performed the same experiment upon both thighs of another large pale frog, leaving the sciatic trunks entire in the first instance, until I had ascertained that the circulation in the feet had not been interfered with. Three hours after this had been done I divided the nerve in the left thigh, and in about forty minutes observed that the leg was decidedly darker below the seat of operation. After another hour I found the pigment stellate in the left webs, whereas it was in the dotted condition in the right foot. I then cut the nerve in the right limb, and within a quarter of an hour the leg was already considerably darker below the wound, and the pigment in the webs had become stellate. Next morning the body was still pale, but the legs were very dark, and they continued to deepen in tint, although the animal was kept in a white earthen jar covered with glass in a bright light, till at about 3 P.M. they were almost absolutely black, while the pigment was diffused in the webs to the extremest degree, the body meanwhile and the upper parts of the thighs retaining their former light colour. The tint of the legs remained unaltered till the death of the animal, which took place several hours later.

The natural interpretation of these results appeared to be, that there exists a constant tendency to diffusion of the pigment in a limb so soon as it is liberated from the influence of the usually recognised nervous centres. It afterwards occurred to me, that if this were really true, diffusion of the pigment might, by proper management, be observed in an amputated limb before the supervention of the tendency to *post mortem* concentration: for I knew, from reasons to be mentioned hereafter, that this effect of death depended on the cessation of the flow of blood through the vessels, and, from what I had seen of arterial contractions in the frog's web, and vermicular movements of the mammalian intestine from a similar cause, I felt sure that, if the blood were retained within the vessels, the arrest of the circulation could not be instantaneous in its effects upon the pigment, but that some minutes would probably be required to develope them; during which time the diffusion resulting from liberation of the pigment-cells from the influence of the ganglia in the trunk would proceed unchecked. Accordingly, on the 3rd of September, 1858, having tied a string tightly round the ankle of a pale frog, I immediately amputated above the ligature, and, avoiding the loss of time involved in tying out the toes, placed the foot at once on a plate of glass with a drop of water, two adjacent toes being kept apart by morsels of moistened lint. Within a minute and a half of the application of the string, the pigment in the web was observed to be in the angular condition, with short simple projecting processes, *i. e.* approaching

stellate, and two minutes later two contiguous cells were sketched in that state. About a minute after this it was evident that diffusion was taking place, and it continued to develope itself during the next ten minutes, at the end of which time the rays of the stellate pigment had shot out complicated offsets. Within the following five minutes, however, it was arrested by *post mortem* concentration, which gradually carried the pigment back to the angular state. This experiment, therefore, furnished confirmation of the view, that, in the ordinary circumstances of the animal, the influence of the central organs of the nervous system is required for the maintenance as well as the development of concentration of the pigment in the limbs.

Supposing this to be established, it would follow that the accommodation of the tint of the skin to that of surrounding objects is certainly not the result of direct action of the rays of light upon the pigment-cells, but a reflex phenomenon; and it was an interesting question whether the afferent nerves concerned were the optic pair, or branches in the skin sensitive to luminous impressions. With a view to determining this point, I completely removed the eyes of a pale frog on the 13th of September, 1858, at 1 P.M., and then placed it in a dark cupboard. During the first hour after the operation it became even paler than before, no doubt in consequence of the injury which had been inflicted *, assuming apparently the lightest possible shade; and this continued with very little change till night, although the animal was still kept in the dark. Next morning it was decidedly darker, and the tint was still deeper at 2^h 25^m P.M. The glass containing the frog was now placed in a bright light, and surrounded on all sides by white objects; but this change produced no difference in the colour of the skin, which continued till 7^h 30^m P.M. of a peculiar dingy hue. It was then put back into the dark place, and at 11^h 40^m P.M. was still exactly the same. On the following day, at 8 A.M., the animal seemed a little paler, and was even lighter at 10 A.M., though still in the dark; so that it was evident that no difference whatever was produced upon its colour by admission or exclusion of light. But that the nervous system generally was in a state quite disposed for acting upon the pigment-cells when subjected to appropriate irritation, was shown by the following circumstances. At the hour last mentioned, the animal, having escaped from the vessel in which it was contained, struggled violently during my attempts to secure it, and in the short time thus occupied changed to almost the palest possible tint. It was then placed at once in the bright light, as before, but, in spite of this, was within ten minutes already decidedly darker, and, half an hour later, was almost coal black, though still subject to the full influence of white light. Just after this observation was made, the frog again escaped, and having again struggled considerably before it was replaced in the glass, it was seen to be within four minutes as pale as when first observed in the morning, but after the lapse of another half hour it was again almost as dark as ever, and continued so till 2^h 30^m P.M., though all the while exposed to the same light. The observations were continued for two more days, during which period the same complete indifference to the brightness or obscurity of surrounding objects was still evinced.

* Probably from the irritation of the optic nerves.

These facts indicated pretty clearly that the eyes are the only channels through which the rays of light gain access to the nervous system so as to induce changes of colour in the skin. But for the sake of confirmation I thought it worth while to perform the following experiment. Two very dark frogs having been obtained, I put a hood of black cloth on the head of one of them, leaving the body and limbs uncovered, an aperture being made in the cloth below the throat for the purposes of respiration, and then placed them both in the same glass vessel exposed to white light. The struggles of the animal while the covering was being adapted and secured, had the effect of making it grow much paler, so that it was of about medium tint when introduced into the glass; while the other, which was from the first the darker of the two, still retained its original coal-black appearance. Half an hour after this had been done, the contrast between them was much diminished, partly in consequence of the dark one having become slightly paler, but much more from the paler having grown darker. After another half hour they were of precisely the same colour, and when another similar period had elapsed, that which was the darker to begin with was distinctly the paler of the two, being much lighter than at first, though still considerably darker than medium. A hood was now placed upon this animal, and that upon the other was removed, and both were replaced in the same light as before. This procedure occupied about ten minutes, and within seven minutes of its completion the creature which had the head uncovered was already the paler of the two, having grown decidedly lighter in colour; while that on which the cap had been last placed seemed somewhat darker; and after another hour, while the latter was still of much the same dark shade, the former, with the head exposed, was very much paler, being about midway between the medium and the palest possible tint. An experiment of the same kind was performed upon another pair of frogs with very similar results, the details of which it is not necessary to mention. I afterwards found that the presence of the hood tends to check diffusion, or even in some cases to give rise to concentration of the pigment, probably by making the animal struggle to throw it off; so that in one instance a frog which was put in a perfectly dark place, immediately after the cap had been put on, grew much paler in the course of two hours. This circumstance prevents the skin from becoming as dark on the application of the hood as it would do if the head could be covered without exciting the animal. This, however, only renders the facts above mentioned more striking, so that they afford of themselves sufficient proof that the direct action of light upon the integument is incapable of affecting the pigmentary functions; and thus the conclusion before arrived at receives complete confirmation from these experiments.

There is of course nothing new in the fact that other functions besides vision may be excited in a reflex manner through the optic nerves; the contraction of the pupil, and the sneezing experienced by many persons on coming suddenly into bright sunshine, being well-known examples of such phenomena. On the other hand, the view that the cutaneous nerves are sensitive to luminous impressions was destitute of any support from analogy*.

* In the chameleon, a part exposed to the sun becomes dark, while the rest of the body remains unaffected.

From the part taken by the second pair of nerves in bringing about the changes in the tint of the skin under the influence of light, and also from the darkening of the hind legs observed to occur after dividing within the canal the roots of the branches which supply them*, we learn that the cerebro-spinal axis is chiefly, if not exclusively, concerned in regulating the functions of the pigment-cells. Considering that those functions have probably a close affinity with the processes of secretion and nutrition, it is interesting to find that they are thus subject to the control of the spinal system.

The circumstance before alluded to, that a dark frog always becomes pale after death, is mentioned both by VON WITTICH and HARLESS, but without any discussion of its cause. This *post mortem* concentration takes place in a limb in spite of amputation, and therefore cannot be due to the agency of any ganglia contained in the head or trunk. Neither can it be the result of failure in action on the part of such ganglia; for if the circulation be artificially arrested in a part of a living frog without interfering with the nerves leading to it, a similar change in the pigment to that which results from death comes on before the nerves have become, so far as we can judge, at all impaired in their functions. This was proved by the following experiment:—On the 7th of June, 1858, having tied the right femoral artery of a moderately dark frog in the middle of its course, I divided it below the ligature, and also cut through, in the same situation, all the soft parts of the thigh except the sciatic nerve with a little adherent muscle. The operation was completed at noon, when the animal was put into a dark place; and at 1^h 40^m P.M. the body generally was darker, but the right leg from the wound downwards was decidedly paler than before; the animal, however, still moved it freely. At 6^h 20^m P.M. the general surface was as dark as ever, but the right foot presented the extreme degree of pallor; yet the creature still moved the leg both spontaneously and when the toes were pinched, showing that the motor and sensor nerves retained their functions. Sensation, however, was not so acute as in the left foot; in the latter a touch sufficed to induce movements in the body generally, whereas in the former a pinch was necessary to produce the same effect. At 10^h 15^m P.M. the same contrast in colour continued, but no movement could be induced in any manner in the pale limb, although obscure indications of a certain amount of sensibility remaining in it were still elicited by forcible pinching.

In this case, concentration of the pigment came on in the limb in consequence of arrest of the circulation through it, several hours before its nerves concerned in sensation and motion had lost their powers, and therefore at a time when we cannot doubt that the ganglia in the trunk had full opportunity for acting on the pigment-cells, which, as we know from experiments before mentioned, are capable of being influenced through the

I have little doubt, however, that this is due to the calorific, not the luminous rays. That heat does produce such an effect, was lately demonstrated to me by Professor GOODSIR upon a living chameleon, which, when held in broad daylight before a dull-red fire for a short time, grew much darker on the side that was warmed, but retained elsewhere its former pale green colour.

* See p. 635.

sciatic trunk. Hence it appears that *post mortem* concentration is the result of the cessation of the flow of the blood through the vessels, and that it is a purely local phenomenon developed in some manner quite independent of the central organs of the nervous system.

The period at which it occurs varies a good deal in different cases. This seems to depend partly upon whether the blood is retained in the vessels or not. Thus in one instance in which a piece of web was cut out, so as to ensure complete escape of the vital fluid, the process was already considerably advanced within nine minutes; whereas in the case above related, in which the blood was retained in the limb by a ligature, concentration did not commence till full a quarter of an hour after amputation. The season of the year also seems to have a great effect. In a cold room, in the depth of winter, I have known some hours elapse before the pigment began to change in an amputated limb: this is probably owing to greater languor in all the vital processes during the period in which the creature naturally hibernates.

The dead frog, if previously healthy, assumes after a while a nearly uniform pale colour, concentration being carried to the extreme degree in all parts. It does not, however, remain in this condition; for when a variable time has passed, the skin becomes again somewhat darker, and on microscopic examination the pigment is found pretty uniformly angular or stellate. Nor are these the only changes to which the pigment is liable after death, as I first became aware in April 1858, when examining an amputated limb with reference to the *post mortem* contractions of the arteries, the blood being retained in the vessels. In that case, after complete concentration followed by slight diffusion had taken place, irregular changes began to appear; some tracts of the web under observation becoming affected with more or less full diffusion of the pigment, while in others it became more concentrated. Then after the lapse of some hours its state was found reversed, being concentrated in parts where it had been diffused, and *vice versâ*. These curious variations continued till so late as the tenth day after amputation, becoming more frequent after the first few days; so that sometimes a considerable alteration was observable within half an hour.

These facts appeared to me of great importance, as proving the continuance of vital actions for a much longer time than had been previously supposed possible in a severed portion of the body. They seem also valuable with reference to the influence of the nervous system over the pigmentary functions; for the circumstance that considerable patches of the web usually had the pigment in the same condition throughout at one time implies that a large number of pigment-cells were acting in concert, and therefore probably under the control of the nervous system, although, as the leg had been amputated, they were of course freed from the influence of the central ganglia. Hence we are led to suspect the existence in the limb of an apparatus, probably ganglionic in structure, coordinating the actions of the pigment-cells, just as we know that the muscular contractions in the mammalian intestine are harmonized by a local mechanism of that

nature, while we have reason to think that the same thing holds regarding the arteries in the frog's web*. Such a view is in accordance with the results of recent anatomical discovery, which has revealed nerve-cells in many parts where their occurrence had not previously been conjectured. But in the absence of more positive evidence, we must be careful not to trust too much to analogy on such a point; for it by no means necessarily follows, that, even if muscular fibre-cells are incapable of acting in mutual harmony without the aid of the nervous system, the same must be the case with pigment-cells, which, it is to be remarked, resemble ganglion corpuscles in being connected together by anastomosing offsets. The nerve-cells, if such be really the means by which the harmonious actions of the pigment-cells in an amputated limb are induced, must be disseminated among the tissues of the web itself; for both *post mortem* concentration and secondary diffusion occur in a piece of a web cut out and placed in a drop of water on a plate of glass. This was ascertained on the 4th of September, 1858, in the case already alluded to as an instance of rapid occurrence of concentration. About half an hour after removal from the body, the pigment, previously reticular, was in the dotted state, and three hours later it was found to be again stellate.

The case of the pigment-cells is analogous to that of the arteries in this respect, that, so long as circulation is going on, they are generally in entire subjection to the central ganglia, and act only when stimulated by their influence. But as, in the arteries, it appears to be by the independent action of the local nerves that a contraction caused by direct irritation spreads to a considerable distance from the part operated on, so it is probably by local means that the pallor induced by pinching the web affects a circle of surrounding tissue. If this be true, the case of direct irritation will be an exception to the general rule, that, while circulation continues healthy, concentration always implies the operation of the central organs of the nervous system.

Comparing the changes in the pigment in an amputated limb with those which take place under similar circumstances in the arteries†, it appears that the first effect of removal from the influence of the nervous centres in the head and trunk is arterial relaxation and pigmentary diffusion, followed in a variable time by contraction of the vessels and concentration of the dark molecules, giving place again to relaxation and diffusion, after which succeed irregular alternations of contraction and dilatation in the one case, and of concentration and diffusion in the other. Here, though the vascular and pigmentary changes do not at all correspond with one another in point of time, yet there is an evident parallel between them; and, admitting that in each case the variations are the result of alternate action and inaction of the appropriate local nervous system, it is evident that concentration of the pigment corresponds to contraction of the muscular fibres of the arteries; these being both the results of nervous action, while diffusion of the pigment, like arterial relaxation, takes place when the nerves cease to operate. It

* See the preceding paper on the parts of the nervous system which regulate the contractions of the arteries, page 619.

† See the preceding paper before referred to, page 618.

will be remembered that a similar conclusion was derived from the study of the influence exerted upon the pigment-cells by the central ganglia. Hence it appears that the tendency to diffusion of the pigment-molecules is in constant operation in the cells, but kept in check by an antagonistic concentrating agency varying in obedience to nervous influence.

It is an interesting circumstance, that two functions seemingly so totally distinct as muscular contraction and pigmentary concentration, should both be thrown into a state of activity in consequence of arrest of the circulation. It is to be remembered, however, that there is no evidence that either the involuntary muscular fibre or the pigmentary tissue is directly influenced by the cessation of the flow of blood, the effect being apparently produced through the medium of the local nervous system. This we know with certainty in the case of the *post mortem* movements of the intestines; and we have seen reason to think it likely that the same is true regarding the contractions of the arteries after death, and the concentration of the pigment under similar circumstances. It is a curious question how the arrest of the circulation causes these actions of the local nerves. The idea suggested by the facts is that the tissues begin to suffer from the want of fresh supplies of the vital fluid, and resent the injury, as it were, by a struggle.

Rich in results of general physiological interest as the study of the pigmentary system of the frog has proved, it has yielded fruit of not less value in a pathological point of view. Indeed, what induced me to investigate the functions of concentration and diffusion, was the unexpected light thrown upon the nature of inflammation by the effects produced by irritants upon those processes. For information on this subject I beg to refer the reader to the next paper in these Transactions.

The pigmentary system also promises to render good service in toxological inquiry. Hitherto, in experiments performed upon animals with that object, attention has been directed chiefly, if not exclusively, to the effects produced upon the actions of the nervous centres, the nerves and the muscles. In the pigment-cells we have a form of tissue with entirely new functions, which, though apparently allied to the most recondite processes of the animal economy, yet produce very obvious effects, and thus afford great facilities for ascertaining whether or not they have been destroyed by any poison that may have been administered.

An experiment of this kind which I once performed, though with a different object, may be mentioned by way of example. Being desirous of confirming the conclusion to which I had been led by experiments above related, viz. that diffusion always tends to take place when the influence of the nerves is withdrawn from the pigment-cells, it occurred to me that the Urari poison might be brought into requisition for that purpose: for it has been shown by Professor Kölliker of Würzburg, that this substance paralyses in the first instance the extremities of the motor nerves without affecting the contractility of the muscular tissue; and supposing the nerves concerned in regulating the pigmentary changes to be similarly deprived of their powers, while the pigment-cells themselves remained intact, diffusion should take place after exhibition of the drug, pro-

vided my view were correct. Accordingly, at $2^h\ 10^m$ P.M. on the 21st of December, 1857, I introduced beneath the skin of the back of a pale frog a portion of Urari extract, for which I was indebted to the kindness of Dr. CHRISTISON. At $2^h\ 25^m$ reflex action was entirely abolished, the creature being to all appearance dead, so far as could be judged by the naked eye, although the microscope showed that circulation continued in the webs. The pigment meanwhile had become stellate, but did not continue in that condition, being, half an hour later, found fully concentrated. Soon after this, however, diffusion again commenced, and continued to advance steadily till circulation ceased early the following morning, at which time the integument was almost black. In the course of a few hours, however, it was brought again back to the palest possible tint by *post mortem* concentration.

The diffusion which ultimately took place in this case was no doubt due to loss of function on the part of the central ganglia or the nerves connecting them with the pigment-cells. But from the occurrence of concentration half an hour after the faculty for reflex action had ceased, we learn that these nerves, like the intrinsic motor nerves of the heart and intestines, remain unaffected by the Urari poison for a considerably longer time than those which excite the contractions of the voluntary muscles. We further learn from the fact that *post mortem* concentration came on as usual, that the pigment-cells retain their powers, and also their capability of acting in mutual harmony after the rhythmical contractions of the heart have been abolished by this poison.

Such experiments are so readily performed, and the effects produced upon the pigment-cells or the nerves which govern them are so obviously indicated by the changes of colour in the integument, that I venture to recommend this method of investigation to those who are occupied in studying the action of poisons.

XXXI. *On the Early Stages of Inflammation.* By JOSEPH LISTER, *Esq. F.R.C.S. Eng. and Edin., Assistant Surgeon to the Royal Infirmary, Edinburgh. Communicated by Dr.* SHARPEY, *Sec. R.S.*

Received June 18,—Read June 18, 1857.

INTRODUCTION.

THE morbid process designated by the term Inflammation, being one to which every organ and probably every tissue of the body is liable, and comprehending as it does in its progress and consequences by far the greater number of the ills to which flesh is heir, possesses a deeper interest for the physician or surgeon than any other material subject which could be named. The practical importance of inquiries tending to elucidate the essential nature of this process, has been for centuries recognized by all enlightened members of the medical profession; for it is obvious that just views regarding it must tend to promote the establishment of sound principles in the treatment of the diseases which it produces. At the present day more especially, when theory is allowed such free scope, and is permitted to attack the most time-honoured rules of practice, we stand in peculiar need of the beacon-light of correct pathology to enable us to steer a safe course amid the various conflicting opinions which assail us. Yet so far from our knowledge of inflammation being in a satisfactory condition, authorities are at variance upon the fundamental question, whether it is to be regarded, in accordance with JOHN HUNTER'S opinion, as active in its nature, and consisting in an exaltation of the functions of the affected part, or whether it should not rather be considered a passive result of diminished functional activity.

In seeking for the solution of this great problem, we cannot expect to gain much from the contemplation of the more advanced stages and results of inflammation, such as copious exudation of lymph, suppuration, ulceration, or gangrene. When any one of these has taken place, the nature of the original disease is masked to a great extent by the subsequent changes; and the cell-development which occurs in lymph after its effusion, is no more proof of activity in the inflammatory process, than the loss of the vital powers in gangrene can be accepted as evidence in the opposite direction. It is upon the first deviations from health that the essential character of the morbid state will be most unequivocally stamped, and it is therefore to the early stages of inflammation that attention must be chiefly directed in this inquiry.

If the palm of the hand be chafed by long-continued friction, as for example in rowing a boat, the first thing that will be observed, when attention has been directed to the part by a feeling of uneasiness, will be that the skin is redder than natural, implying

that the vessels are abnormally loaded with blood, and if the irritation be continued, the cuticle will be raised in the form of a blister. If, now, the loosened epidermis be artificially removed on the earliest occurrence of effusion, a scarlet raw surface will be exposed; and on pressing the tender dermis firmly with the finger, and suddenly removing the pressure, it will be found that while the redness will for the most part have momentarily disappeared, there will be many minute red points from which the blood cannot be expelled. This shows that, while the blood is in part still free to move, there are some minute vessels completely clogged with it. Again, if a portion of mustard be placed on the skin covering the dorsal aspect of one of the fingers, abnormal redness will very speedily be produced, which in the first instance disappears completely on pressure; but, if the mustard has been kept on long enough, can be only imperfectly dispelled; and if the application be still longer continued, vesication will be the result. I had lately the opportunity of examining the brain of a man who had died of tetanus, complicated with incipient meningitis; the *post mortem* appearance of the latter being maculiform congestion of the pia mater. Having stripped off a portion of the affected membrane, and carefully washed away with a camel's-hair brush the cerebral substance adhering to it, I applied the microscope to one of the affected spots, and found that all the minute vessels were filled with crimson blood, while those of the surrounding parts were comparatively pale. It was evident that the red corpuscles were, in the former, so closely crammed together as to produce the appearance of a uniform mass, while in the latter they were present only in their usual proportion to the liquor sanguinis. Thus it appears that in the human subject, inflammation, whether induced by mechanical irritation or by an acrid application such as mustard, or of spontaneous origin, is characterized at an early period by a certain amount of obstruction to the progress of the blood through the minute vessels; a phenomenon, which it is therefore of great importance to understand.

It fortunately happens, that we have, in the transparent web of the frog's foot, an opportunity of observing with the utmost facility the circulation of the blood in the living animal, and of watching the effects produced upon it by irritating causes. It may naturally appear very doubtful whether observations made upon creatures so low in the animal kingdom as the Amphibia, can with propriety be brought to bear upon human pathology. A few facts will, however, suffice to show that no such doubts need be entertained. If a portion of moistened mustard be placed upon the web of a frog, tied out under the microscope, the blood-vessels will soon be found abnormally red; and if the application be continued long enough, all the capillaries will become choked with corpuscles so closely packed as to present the appearance of a uniform crimson mass; and by and by the epidermis will be found raised in the form of a blister over the part on which the mustard lay. These effects are precisely similar to those which we have seen to be produced by it upon the human skin; and before effusion has taken place, the vessels of the affected part exactly resemble those of the congested spot of inflamed pia mater above described. Again, if dry heat be made to act upon a part of the frog's foot,

there will result, in proportion to the elevation of the temperature and the duration of its action, undue redness of the vessels from accumulation of the blood-corpuscles; and if the burn have been sufficiently severe, vesication will soon take place as in the human subject. These and other similar cases indicate that the early stages of inflammation are alike in man and in the frog, and this conclusion is fully confirmed by examination of the bat's wing, which furnishes the means of watching the effects of irritants upon mammalian circulation. The very small size of the blood-corpuscles, and some other circumstances, render that animal much less suitable for the investigation than the frog; but with the use of high powers of the microscope and a little pains, the same sort of experiments can be made with both: and the careful observations of Messrs. PAGET and WHARTON JONES, and, I may add, also my own more limited experience with the bat, have shown that in all the details that can be observed, a complete similarity obtains between the effects of irritation upon the circulation in the two creatures. We may therefore rest fully satisfied that conclusions arrived at from the study of the early stages of inflammation in the foot of the frog will apply in all strictness to the same morbid process in man.

It is well known that the field of observation thus afforded has not been allowed to remain uncultivated. Since the microscope has been brought to its present state of perfection, not to speak of a previous period, men of established scientific reputation have devoted much patient labour to it; and any one who now enters upon this inquiry has the great advantage of possessing faithful records of accurate observations made by many able predecessors. But the number and discordance of the views entertained by different authorities regarding the cause of the "stasis" of the blood in inflammation, are sufficient evidence either that the subject demands further investigation, or else that it lies beyond the reach of human means of research.

Having been called upon in the capacity of a teacher of surgery to attempt an explanation of the matter to others, I felt bound to do my best, by personal observation, to form a judgement for myself; and several new facts which I have unexpectedly met with appear to throw such fresh and clear light upon the nature of disease, that I venture to submit them to the Royal Society.

SECTION I.

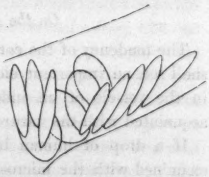
On the Aggregation of the Corpuscles of the Blood.

The tendency of the corpuscles of the blood to aggregate together, constitutes, as we shall see, an important element in the cause of the obstruction which they experience in the vessels of an inflamed part. It is therefore desirable that we should be acquainted with the nature of the phenomenon.

If a drop of human blood just shed is placed between two plates of glass and examined with the microscope, the red corpuscles are seen to become applied to one another by their flat surfaces, so as to form long cylindrical masses like piles of money, as first observed in 1827 by my father and Dr. HODGKIN; and the terminal corpuscles of

each "rouleau" adhering to other rouleaux, a network is produced with intervals of colourless liquor sanguinis. Rapid movement of the blood prevents this occurrence, but it commences as soon as the corpuscles approach to a state of quiescence, and I have seen short rouleaux already present in a drop drawn from my own finger within ten seconds of its emission. In this respect the aggregation of the red corpuscles differs from the coagulation of the fibrine, which does not begin till some minutes after withdrawal from the vessels. There is, in fact, no connexion whatever between the two processes, as is clear from the circumstance that if a drop of blood is stirred with a needle while coagulation is taking place, so as to remove the whole of the fibrine, the corpuscles, which have been separated from one another by the agitation to which they have been subjected, aggregate again in the serum in the same manner as they did at first in the liquor sanguinis. The beautifully regular form of the long masses of corpuscles has suggested to some persons the idea of the operation of some peculiar vital attraction in their formation, while by others the aggregation has been supposed due to merely physical causes, but has never, I think, received a complete explanation. For my own part, I am satisfied that the rouleaux are simply the result of the biconcave form of the red discs, together with a certain, though not very great degree of adhesiveness, which retains them pretty firmly attached together when in the position most favourable for its operation, namely, when the margins of their concave surfaces are applied accurately together, but allows them to slip upon one another when in any other position. There is never to be seen anything indicating the existence of an attractive force drawing the corpuscles towards each other: they merely stick together when brought into contact by accidental causes. Their adhesiveness does not affect themselves alone, but other substances also, as may be seen when blood is in motion in an extremely thin film between two plates of glass, when they may be observed sticking for a longer or shorter time to one of the surfaces of the glass, each one dragging behind it a short tail-like process; and as the movement of the blood diminishes so as to permit the formation of rouleaux, the latter may be not unfrequently seen adhering in the same way by one of their terminal corpuscles, as represented in the accompanying diagram.

That the cylindrical character of the aggregated masses is an accidental result of the shape of the blood-discs, is evident from the fact, that in the frog, although the same tendency to agglutination of the corpuscles exists as in Mammalia, yet, as their biconvex form renders it mechanically impossible for them to be applied to one another throughout their entire circumference, they become arranged in groups of an irregular form, as is shown in the annexed sketch of blood contained in a small vein of the frog's web.



Again, different specimens of mammalian blood differ very much in the amount of adhesiveness of their corpuscles; and when this property exists beyond a certain degree,

the discs stick together by any parts that happen to come first in contact, and retain that position more or less, so that the result is the formation, not of rouleaux, but of irregular confused masses. The most striking example which I have seen of this was presented by the blood of a bat, which had lived some days after having been severely wounded. In that case, chains of red discs might be seen adhering firmly by their edges, notwithstanding considerable force of traction operating upon them, and before they at last gave way, tail-like processes of considerable length were drawn out between every pair of corpuscles, indicating that they were very adhesive. These facts seem sufficient proof of the correctness of the view above expressed regarding the cause of the rouleaux.

The adhesiveness of the red corpuscles does not appear to be a vital property. When the fibrine has been removed from a drop of blood during the progress of coagulation, the rouleaux will form again, after being broken up, as many times as the experiment is repeated, until the blood becomes thick from dryness; and if evaporation be prevented by Canada balsam placed round the plate of thin glass, with suitable precaution against the approximation of the two plates, the rouleaux will remain perfect for several days (*e. g.* fourteen in one experiment of the kind), after which the very slow chemical action of the balsam upon the blood gradually renders it confusedly red and opaque. Gum mixed with blood seems to preserve it, like a pickle, from decomposition for a very considerable period; and if a piece of wet lint be suspended above such a specimen so as to prevent evaporation, the corpuscles will retain their adhesiveness for a long time (*e. g.* twenty-four days in one instance), until the water communicated to the mixture by the artificially damp atmosphere gradually renders them non-adhesive. These experiments were made in winter, when the low temperature prevents rapid decomposition; but it appears unlikely that even at that period of the year a part of the human body should retain any vital properties after having been left three and a half weeks mixed with strong gum, which, it is to be observed, alters very much the form and appearance of the corpuscles.

Both in man and in the frog the white corpuscles also are found aggregated together more or less in a drop of blood examined microscopically, and indeed they adhere much more closely than the red ones both to the glass and to one another; but as they are not disc-shaped, but globular, they do not become grouped into rouleaux, but into irregular masses, which, in consequence of their colourless and transparent character, are apt to pass unnoticed, or to be mistaken for masses of coagulated fibrine. If a portion of blood be allowed to run in between two plates of glass nearly in contact with one another, the white corpuscles will be found sticking together near the edge of the glass at which the blood entered, the blood having been as it were filtered of white corpuscles as it passed on; and this is not due to the greater size of the colourless corpuscles than the red, for I have seen it occur with frog's blood when there was room enough between the plates for the red corpuscles to lie edgewise, their transverse dimensions being greater than the diameter of a white corpuscle.

The red corpuscles also often adhere to the colourless ones.

It will be seen hereafter that the corpuscles of blood within the vessels of the living body present great varieties of adhesiveness, according to the amount of irritation to which a part may be subjected; such variations are also met with in blood outside the body, in consequence of differences in the quality of the plasma.

If a drop of very thick solution of gum-arabic, freshly prepared and free from acidity, be added to about four drops of blood, the red corpuscles of the mixture will be found to aggregate much more speedily and more closely than those of ordinary blood, a fact ascertained some years ago by Mr. WHARTON JONES and some other observers *. The result is the formation of dense orange masses with large colourless interspaces, but without much regular appearance of rouleaux. On closely examining such a specimen, the red discs are seen to be much diminished in breadth and increased in thickness, and exhibit an extreme degree of adhesiveness, sticking together indifferently by their edges, or any other parts that happen to come first; and if one of the masses be stretched so as to break, the separating corpuscles become drawn out into long viscid processes, which at length give way in the middle, and each half is drawn into its respective corpuscle.

This remarkable effect cannot be accounted for by the mere viscidity of the plasma, which would not make the corpuscles adhere to each other more intimately than usual, unless they had themselves experienced some change, of which, indeed, their altered form is conclusive evidence. Further, if a very small quantity of acetic acid be added to the gum before mixing it with the blood, the corpuscles will be found to have lost altogether their adhesive character, although the mixture may be made viscid to any degree that may be desired. A little acid perspiration on the finger appears to prevent entirely the formation of rouleaux in a drop of blood taken from it; but after the finger has been washed, the usual appearances present themselves when more blood is drawn. Diminished adhesiveness of the red corpuscles is also the earliest evidence of the chemical action of tincture of cantharides and croton oil on the blood of the frog. A similar effect is produced when a drop of human blood is shed into a little fresh almond or olive oil on a plate of glass, and stirred slightly so as to break up the blood into minute drops. On microscopic examination of such a mixture, one sees the red discs aggregated as usual in the interior of the larger drops; but at their exterior, which is in contact with the oil, and throughout the smaller drops, the corpuscles are somewhat altered in form, being of less diameter, but thicker, though still in the form of discs, and at the same time they are found to have lost every trace of a tendency to adhere together; and when present in a thin layer of blood they stand apart at equal distances from one another, as if exercising a mutual repulsion, at the same time exhibiting molecular movements. If a drop of blood freshly shed upon a glass plate be stirred with a needle in an atmosphere of chloroform vapour, the rouleaux will be found to form less perfectly in proportion to the time that the chloroform has acted, until, if the period be as long as

* Guy's Hospital Reports, vol. viii. p. 73.

thirty seconds, the corpuscles will be all cup-shaped, and will exhibit no disposition to aggregate. But no effect is produced on the formation of the rouleaux by stirring a drop of blood in the same way for a much longer time in an atmosphere free from chloroform. The aggregation of the corpuscles is not prevented merely by their becoming cup-shaped, and therefore unable to apply themselves to each other as usual. For the vapour of caustic ammonia, while it renders the corpuscles cup-shaped, seems rather to increase than to diminish their adhesiveness and aggregating tendency, and a temperature of about 32° FAHR. has similar effects with the alkali*. Even in the mixture of blood and gum many of the corpuscles are cup-shaped, though adhering together with peculiar tenacity.

Whether or not it will ever be possible to explain these curious facts upon chemical principles seems very doubtful; but in the meantime, what appears most striking about them, and what most concerns the present inquiry, is that great effects may be produced upon the adhesiveness of the red corpuscles, both in the way of increase and diminution, by very slight changes in the chemical qualities of the plasma.

The galvanic current produces no effect upon the aggregation of the red corpuscles, either of man or of the frog, as I have ascertained by placing the fine platinum wire extremities of the poles of a powerful battery a short distance from one another between two slips of glass beneath the microscope, then completing the circuit by shedding a drop of blood between the plates, and immediately observing the result. In several such experiments I invariably found that aggregation took place as usual, and the only effect produced by the galvanism was a chemical change in the blood, dependent on electrolysis, gradually developing itself in the immediate vicinity of the poles, and causing solution of the corpuscles.

* Since this paper was read, I was told by a gentleman well known in the scientific world, that he had observed, many years ago, that if blood was shed upon a plate of glass previously heated to the temperature of 100° FAHR., the red corpuscles showed no disposition to aggregation till the glass cooled, when the blood became killed, as he supposed, by the unnaturally low temperature. This appeared to me entirely irreconcileable with the fact, that in the frog the red corpuscles aggregate immediately after the blood has been shed, although there is no material difference between the temperature of the air and that of the body of the animal. But, if true, it would have important bearings, to which I need not here allude, upon the essential nature of inflammation. I have therefore thought it well to make some experiments upon the point. The plate of glass upon which the blood was to be placed was warmed by immersion in water of a known temperature, and quickly but carefully dried. A drop of blood from my own finger was then at once shed upon it, and without loss of time covered with a piece of thin glass, which had been kept warm by being laid upon a metallic plate of the same temperature as the water. By proceeding in this way, I was able to make observations upon the blood very soon after it had been shed; and when the glass was about 100° FAHR., the aggregating tendency was found just the same as in ordinary cases, and I detected short rouleaux already formed within five or six seconds of the escape of the blood from the vessels of the finger. The same state of things continued when the water was as high as 136°; but when its temperature was carried up to 155°, the red corpuscles lost their disc-shape and some of them appeared to become broken up, and no rouleaux were formed either while the blood remained warm or after it had cooled. From these results, it is evident that heat does not interfere at all with the aggregating tendency of the corpuscles, unless it is sufficiently great to act upon them chemically.

The buffy coat in inflammatory blood was first explained by Mr. WHARTON JONES*, who showed that it resulted from the red corpuscles aggregating more closely than usual, and therefore falling more rapidly through the lighter plasma, so as to leave the upper portions completely before the occurrence of coagulation. It was supposed by the same authority that this peculiarity of the red discs was due to increased fibrine in solution, rendering the liquor sanguinis abnormally viscid, and so operating like the admixture of gum above alluded to. But the fact that the corpuscles aggregate as closely after the fibrine has been removed as before, appears quite opposed to such a view. I have examined many drops of my own blood, before and after the removal of its fibrine, with the special object of ascertaining this point, and have never been able to detect any material difference between the aggregation in the two sets of cases. In the blood of the bat before mentioned, which was probably suffering constitutionally from inflammation, the corpuscles continued to retain their excessive adhesiveness for a whole hour after coagulation of the fibrine. I once made a similar observation on a specimen of horse's blood †, which, as is well known, presents the buffy coat in the state of health. Having divided the clot vertically several hours after coagulation had occurred, my attention was attracted, on looking at the section, by minute red points, like grains of sand, lying in the lower part of the buff, just above the coloured portion of the coagulum. On microscopic examination of a small piece containing some of them, they proved, as I expected, to be masses of aggregated red corpuscles, but with the peculiarity of being compact and globular instead of presenting the usual appearance of a network of rouleaux, and it was evident that the corpuscles had been excessively adhesive at the time when aggregation took place. Some of the red discs were now squeezed out from the fibrinous mass in which they lay, and as they escaped into the surrounding serum they at once adhered firmly in that fluid, forming again compact globular masses, such as, if in freshly-drawn blood, would necessarily give rise to the buffy coat; so that their adhesiveness seemed to have been in no way affected by the withdrawal of the fibrine from solution. It may of course be urged, that the fibrine, when in solution, may have impressed upon the corpuscles an adhesiveness which they retained after soaking for hours in serum, but this seems a very unlikely hypothesis. I suspect, therefore, that the peculiarities of the corpuscles of inflammatory blood are the result of other changes than the excess of fibrine.

From the facts detailed in this section, it appears that the aggregation of the corpuscles of blood removed from the body depends on their possessing a certain degree of mutual adhesiveness, which is much greater in the colourless globules than in the red discs; and that, in the latter, this property, though apparently not depending upon vitality, is capable of remarkable variations in consequence of very slight chemical changes in the liquor sanguinis.

* British and Foreign Medical Review, October, 1842.

† This observation was made subsequently to the reading of the paper, viz. in November, 1857.

SECTION II.

On the Structure and Functions of the Blood-vessels.

An acquaintance with the anatomy and physiology of the vascular system is indispensable to a successful study of the deviations from health exhibited in the circulation of the blood through the vessels of an inflamed part; it is not, however, intended to give here a full account of the subject, but merely to dwell upon some important points on which differences of opinion prevail.

It has long been a debated question whether or not the capillaries possess contractility, and there is still some difference of opinion among authorities upon the subject. With a view to throwing light upon this important point, I investigated carefully the structure of the minute vessels of the frog's foot; dissecting them out from between the layers of skin composing the web, so as to render their constituent material capable of clear definition with the microscope. The chief results have been communicated to the Royal Society of Edinburgh, in a paper that will shortly appear in their Transactions, "On the Structure of Involuntary Muscular Fibre*." I need therefore merely repeat here, that while the capillaries were proved to consist, as has been long known, merely of a delicate homogeneous membrane beset with occasional nuclei, the minute arteries, some of them even less in calibre than average capillaries, were found to possess three distinct coats, namely, an external layer of cellular tissue, in variable quantity, longitudinally arranged, an internal extremely delicate lining membrane, and an intermediate circular coat, which constituted the principal bulk of the vascular parietes, and which, when highly magnified, was found to consist of a single layer of muscular fibre-cells, each wound spirally round the internal membrane so as to encircle it from one and a half to two and a half times.

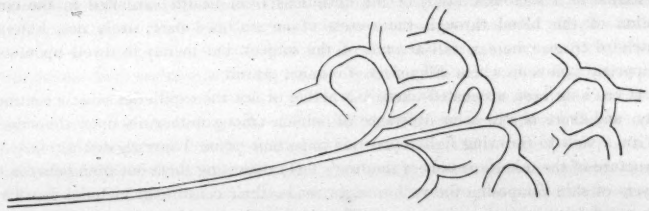
Now when we consider the properties of muscular fibre-cells, which, as is shown in the paper referred to, are capable of contracting in the pig's intestine as much as to one-tenth of their length, it is impossible to conceive a more efficient mechanism for the constriction of a tube than is provided in these minute arteries. On the other hand, the capillaries are totally destitute of any structure known to be contractile. The changes of calibre which occur in the vessels of the living web are in perfect harmony with this anatomical description; for while the arteries, even to their smallest branches, are sometimes constricted to absolute closure, and at other times widely dilated, the capillaries are never found to be entirely closed, nor to present any variations in diameter, which are not explicable by elasticity of their parietes†.

The sketch at the top of the next page represents the calibre of an artery dividing into minute branches, with the capillaries into which they poured their blood. At the time when it was drawn, the artery and its branches were in a state of spontaneous

* Transactions of the Royal Society of Edinburgh, vol. xxi. pt. 4.

† In this respect I merely confirm the observations long since made by Messrs. Paget and Wharton Jones.

contraction, yet the capillaries retained their full average dimensions. After a while the artery became so much more contracted as only to admit single corpuscles even through the main trunk; yet still the capillaries fed by it did not appear affected in calibre. This is but one example of what I have observed times without number.



The capillaries, though not contractile, are highly elastic, and by virtue of this property are capable of considerable variation in capacity, according to the distending force of the current of blood. Figs. 3 and 4 of Plate XLVII., traced with the camera lucida, show, besides the pigment in two chromatophorous cells of the frog's foot, part of a capillary in nearly extreme conditions in point of calibre. In fig. 3 the vessel is about equal in diameter to the length of a red corpuscle, while in fig. 4 it is so narrow that the corpuscles in it are pinched transversely and elongated. When the capillaries are most distended, their parietes are much thinner than when shrunk to their smallest dimensions; an estimate may be formed of the difference by comparing the close proximity of the corpuscles to the outer bounding line of the vessel in fig. 3 with the considerable interval in fig. 4, that interval representing the apparent thickness of the wall of the vessel. It is to be observed that the frog had been killed in a manner involving considerable hemorrhage before fig. 4 was traced, so that the capillaries were then little, if at all, distended with blood. The thinness of the walls of the capillaries, as compared with the small arteries, is, doubtless, calculated to favour the mutual interchanges which must take place between the blood in them and the tissues in their vicinity.

It is believed by some eminent authorities that mutual attractions and repulsions subsisting between the nutrient fluid and the tissues among which it flows, become a source of movement in the blood and assist its flow through the capillaries; while others regard the heart as the sole cause of the circulation: and the difference of opinion on this fundamental point in physiology involves discordance in pathological theory, for some who hold the former view consider the changes which occur in the circulation at the commencement of inflammation, to be principally owing to modifications of the 'vital' moving force*. The view that such a cause of movement exists, has been supported partly by argument drawn from the phenomena of inflammation: but these, as we shall

* See 'Outlines of Pathology and Practice of Medicine,' by W. P. Alison, M.D., F.R.S.E., &c. 1844, pp. 115 *et seq.*

see, require a very different interpretation. It has also been based upon a supposed analogy between the circulation of the blood in the higher animals and certain movements observed to occur without any visible source of mechanical power in tubes and cells in the vegetable kingdom, and, as was thought, also in some of the lower forms of animal life: but though a resemblance may probably exist between some of these and the movements occurring in the processes of secretion and absorption and the circulation of nutrient fluid among the tissues of intercapillary spaces and non-vascular parts, the progress of modern discovery tends to show that the comparison is altogether inapplicable to the sanguiniferous system. It would, I think, be out of place to enter fully into this discussion on the present occasion, but my own experience with the frog leaves no doubt in my mind that in that animal contractions of the heart are the only cause of the circulation. I will content myself with mentioning two observations bearing upon this question. The first of these has reference to certain movements which occur for a considerable time after cessation of the heart's action, and which, though of trivial and uncertain character, have had much stress laid upon them in this discussion. I have ascertained by observations made in several different cases, that they are produced by occasional spontaneous contractions and relaxations of the arteries. These changes in the calibre of the vessels continue, even in an amputated limb, for days after severance from the body*: I have repeatedly watched them taking place, and seen them give rise to the movement of the blood.

The other fact to which I will allude, appears to me to decide of itself the question at issue. Having occasion to examine, under chloroform, some very small frogs, measuring about an inch from the tip of the nose to the end of the coccyx, I found that the blood in the capillaries invariably flowed in a stream pulsating synchronously with the beats of the heart, which were visible through the parietes of the thorax; and however mildly the anæsthetic was administered, the motion was commonly exceedingly slight between the pulses. Not unfrequently, although the arteries remained of full size, the blood moved in jerks, with considerable intervals of absolute stillness between the successive impulses which the contractions of the heart occasioned; yet no accumulation of corpuscles was produced in the capillaries, however long the animal was kept under observation. Had any other cause of motion than the action of the heart operated upon the blood, there must have been a continuous flow, however much accelerated at each pulse; for I must add, that there was nothing whatever of recoil after each onward movement, nor anything indicating obstruction to the progress of the blood.

Thus in these cases of intermitting capillary flow, it was matter of direct observation that the heart was the sole cause of the blood's motion; and as we know that in an animal under the influence of chloroform the changes of the blood from arterial to venous, and *vice versâ*, continue to occur in the systemic and pulmonary capillaries, and as we have every reason to believe that the processes of nutrition in the different parts

* See the preceding paper on the parts of the Nervous System which regulate the contractions of the arteries, p. 618.

of the body go on then as usual, these cases appear to prove absolutely that the forces which are concerned in the mutual interchanges between the tissues and the nutrient fluid do not cause any movement whatever.

But even supposing that it were admitted, for the sake of argument, that the vital affinities do, under ordinary circumstances, cause some movement of the blood, but lose that power in an animal under chloroform, such an admission would hardly affect the discussion regarding the cause of stagnation in inflammation; for in a frog fully under the influence of the anæsthetic, in which, as we have seen, the heart is the only cause of circulation, all the phenomena that result from irritation of the web take place precisely in the same manner as in one to which the narcotic has not been administered. The fact that the heart, even though much enfeebled by chloroform, is capable, unaided by any other force, of maintaining the circulation for an indefinite period without the occurrence of obstruction in the capillaries, or any undue accumulation of corpuscles in them, affords positive proof that any other cause of movement which may be conceived to exist when chloroform has not been given, must be altogether insignificant, and that the cessation of its operation does not give rise to stagnation of the blood*.

The veins of the frog's web afford very little evidence of contractility; but a small amount of unstriped muscular tissue, transversely arranged, is distinctly to be seen in the larger venous branches; and on one occasion I observed a very considerable degree of local contraction, as measured from the outer borders of the external coat of a vein running through a small area which I had pinched forcibly with forceps. I have also seen one expand on sudden dilatation of the arteries of the web, so that its diameter increased from twelve to fourteen degrees of a micrometer; but this is perhaps explicable by elasticity†.

It has been already mentioned that the arteries undergo spontaneous variations of calibre. Such changes are constantly going on at varying intervals, there being nothing of a rhythmical character about them. A struggle on the part of the animal is

* Dr. SHARPEY has for many years alluded in his lectures to the circumstance that, the weaker the animal, the more do the effects of the successive cardiac impulses show themselves in the capillaries of the webs, as evidence that the action of the heart is sufficient to account for the circulation. He also informs me that he has frequently verified the observation of SPALLANZANI, that in the gills of the tadpole the flow of the blood ceases completely in the intervals between the pulses produced by the ventricular contractions.

† Since the reading of this paper I have noticed striking examples of the contractility of the larger veins in the higher animals. Thus, on exposing the jugular in a living calf, I have seen a particular part of the vessel irritated by the process of dissection shrunk to about a third of its previous calibre. In the human subject, too, when amputating lately at the shoulder-joint on account of contusion inflicted by machinery upon a previously healthy limb, I noticed the axillary vein reduced to about half its natural calibre at the part where it was divided, which was in the immediate vicinity of the injury. I have also had occasion to observe the *post-mortem* contractions of the subcutaneous veins of the sheep's foot, which are carried to such an extent as to reduce the vessels from the size of a crowquil to about that of a darning-needle. The minute veins also sometimes exhibit great contractility in the higher animals, as in the irregular constrictions often seen in those of the mesentery of the mouse, and in the remarkable rhythmical variations in calibre discovered by Mr. WHARTON JONES in those of the bat's wing (Philosophical Transactions, 1852).

generally accompanied by a very considerable constriction of the arteries, and sometimes by absolute closure of them. The contraction usually begins a very short time before the motions of the body, so that the struggle can commonly be predicted by the appearance of the vessels; and dilatation occurs when the creature becomes quiet. Hence the changes of calibre are evidently under the control of the nerves. An account of an inquiry into the parts of the nervous system by which this control is exercised, will be found at p. 607 of this volume; and from the experiments there recorded, it will be seen that either extreme constriction or full dilatation of the arteries of the web may be induced at pleasure, by operating upon the spinal cord. A very good opportunity is thus afforded for studying the effects produced upon the capillary circulation by changes of calibre in the arteries, without employing any means acting directly upon the foot. This is a matter of very great importance, for applications made to the web for the purpose of inducing alterations in the dimensions of the vessels, give rise at the same time to other consequences of irritation, which complicate such experiments in a most deceptive manner, so as to have misled, as I believe, some of the best observers who have devoted attention to this subject.

The following account embodies the results of numerous observations in which this source of fallacy was carefully avoided, the variations in the calibre of the vessels being generally either induced by operations on the cord, or else such as occurred spontaneously.

In a perfectly healthy state of the web with the heart beating powerfully, when the arteries are of about medium width, the current of blood in them is so rapid that the individual corpuscles cannot be discerned; but in the capillaries, whose aggregate calibre is very much greater than that of the arterial trunk which feeds them, the flow is so much slower that they can be pretty clearly distinguished. When the arteries are fully dilated, if the heart continues to act with the same energy, the blood appears to move as rapidly in them as before, though of course in much larger quantity; while in the capillaries the flow is extremely accelerated, so that it becomes as impossible to see the blood-corpuscles in them as in the arteries. On the other hand, when the arteries are considerably constricted, the blood moves more slowly through the capillaries than when the tubes of supply are of medium size, and at the same time the narrowed arteries appear to filter the blood more or less of corpuscles, which are found in smaller numbers in proportion to the liquor sanguinis in the capillaries: and if the constriction of the arteries is sufficiently great, the web is rendered quite pale in consequence of the small number of corpuscles in it, which nevertheless continue to move among the tortuous capillaries, producing in the field of the microscope an appearance something like that of a few flies playing about in a room. Finally, if the arteries are completely constricted, all appearance of flow in the capillaries vanishes, and the web has a wholly exsanguine aspect. Under these circumstances, even the veins, though still of large calibre, may contain little besides colourless liquor sanguinis, which has continued to ooze through the contracted arteries when the corpuscles have been completely arrested; and so incon-

spicuous do the veins become in consequence of this change in the quality of their contents, that it may be extremely difficult to distinguish them from other tissues; the appearance of the web on superficial observation being as if it possessed no blood-vessels at all. This remarkable condition, which, so far as I know, has not been before described, may last for several minutes in consequence of irritation of the cord, and in one case I observed it occur spontaneously, and continue for five minutes together. It appears to be comparable to the dead whiteness of the human fingers when benumbed with cold, or the perfect pallor of the cheek in faintness; while blushing is no doubt caused by full dilatation of the arteries.

Such, according to my experience, are the effects produced upon the circulation by changes of calibre in the vessels of a perfectly healthy web. The arteries regulate by their contractility the amount of blood transmitted in a given time through the capillaries, but neither full dilatation, extreme constriction, nor any intermediate state of the former is capable *per se* of producing accumulation of corpuscles in the latter.

SECTION III.

On the Effects of Irritants upon the Circulation.

It is well known that the application of an irritant substance to the web of the frog's foot is followed by changes of calibre in the blood-vessels, and also by an abnormal accumulation within them of the corpuscular elements of the blood. The first experiments which I performed upon the frog were directed to the solution of the much-debated question, whether or no the latter were a mere consequence of the former; and although it has, I think, been sufficiently shown at the conclusion of the last section that such cannot be the case, yet it will be well to allude shortly to these experiments on account of their further bearing upon the subject of this inquiry.

It occurred to me, that if, instead of the powerful irritants commonly used in these investigations, some exceedingly mild stimulant were employed, the changes in the calibre of the vessels might perhaps be produced without concomitant alterations of the blood. The material which appeared most suitable for this purpose was warm water, which is known to cause, in the human subject, increased redness without inflammation of the part to which it is applied.

Accordingly, in September 1855 I endeavoured to ascertain its effects upon the frog. In most of the experiments, the foot of the animal being stretched under the microscope upon a glass plate somewhat inclined, so that any fluid upon it might run off quickly, an assistant threw a stream of water of known temperature upon it by means of a syringe, the eye of the observer being kept over the microscope, which was provided with a micrometer in its eyepiece. In this way the effects produced by the water could be seen almost immediately after it had ceased to play upon the web, and the changes of calibre in any artery selected for observation were noted with precision. It was found that the result of the warm application was constriction of the arteries to absolute

closure, generally lasting for several seconds*, and then giving place to dilatation beyond their original dimensions, to which they afterwards gradually returned. The dilatation differed in different instances, being generally more decided and more permanent when the water was hotter and longer applied†. In one case, water at 100° thrown upon the web for a brief period caused constriction for a few seconds in the artery under observation, followed by dilatation. While the vessels were still above their usual calibre, more water of the same temperature was applied as before, and again induced contraction followed by abnormal dilatation, which was again made to give place to constriction by a third similar application: the experiments were repeated within a few seconds of each other.

When water not higher in temperature than from 110° to 140° was thrown for not longer than a second or two upon a perfectly healthy web, the changes above described in the diameter of the arteries produced effects upon the flow of blood through the capillaries, precisely similar to those mentioned at the conclusion of the last section. Thus in one such case the constriction of an artery lasted for several seconds, and was in the first instance so tight as to prevent any flow in the field of capillaries supplied by it; then relaxing slightly, it allowed single corpuscles to pass along it with great difficulty, so that the blood became almost entirely filtered of its particles, and at the same time the force of the heart being to a great extent taken off from the elastic capillaries, liquor sanguinis almost destitute of corpuscles flowed in slow pulsating streams along the veins: finally, the dilatation becoming complete, blood of ordinary appearance rushed through with great rapidity.

If, however, such experiments had been several times repeated upon the same foot, and more especially if the warm water had acted for longer periods, another class of symptoms began to show themselves; the corpuscles passing on less freely than the liquor sanguinis through the capillaries, and lagging behind so as to accumulate in abnormal proportion to the plasma, and stagnating completely when the force of the heart was partially taken off through contraction of the arteries, though passing on again when the vessels dilated‡.

* The period of constriction varied much in different instances, and it sometimes passed off (if it occurred at all) before it could be observed. It was best marked in a case, in which, the animal being very quiet, chloroform was not employed. The anæsthetic appears to impair the functions of the spinal cord as a regulator of the calibre of the vessels; and its administration is generally followed by their dilatation.

† Water of the temperature of the room applied in the same way after warm water had been several times employed, caused complete constriction of the arteries, lasting for several seconds; but the subsequent dilatation was very little if at all beyond the normal calibre.

‡ This effect of arterial contraction in producing accumulation and stagnation of corpuscles in the capillaries has been described by Mr. Wharton Jones as occurring in a state of health (*vide* Guy's Hospital Reports, *loc. cit.*). The reason of this I believe to have been, that much greater care than is generally supposed is required in order to avoid any irritation whatever of the delicate webs. The vicinity of the warm hand is particularly apt to produce this effect; and I have known it, when continued for a quarter of an hour, cause complete stagnation of the blood throughout the webs, while a very much shorter period is sufficient to induce a decidedly abnormal condition. I have myself only become fully aware of the great susceptibility of the foot of the frog to injury from warmth since the reading of this paper. An unhealthy

Thus in one case an artery under observation measuring 2° (degrees of the micrometer), the blood was flowing in all the capillaries supplied by it, though containing a very abnormal amount of corpuscles. After a few minutes, the vessel contracted spontaneously to $1\frac{1}{4}$°, and though this was only about a medium width, the flow of the blood became much retarded in the capillaries, and in one of them ceased almost entirely. Water of 115° FAHR. being then thrown upon the web, the calibre of the artery was raised to above 2°, and the flow was resumed in all the capillaries. A few minutes later the vessel again contracted spontaneously to $1\frac{1}{2}$°, when stagnation of the blood became nearly complete in a few of the capillaries. Water at 120° was then applied and caused constriction to a further degree, followed by dilatation to above 2°: during the constriction, the blood scarcely moved at all in the capillaries, but on the occurrence of the dilatation it again flowed in all of them.

If the applications were still further continued, the red discs became more and more closely packed, till at last they were crammed together so as to produce a uniform crimson mass, unaffected by the heart even in the widest state of the arteries.

It was perfectly clear that in these experiments the stagnation of the blood depended on something more than mere contraction of the arteries; and it also appeared impossible to account for it satisfactorily as a result of their dilatation. That inflammatory stasis might occur independently of alteration in the calibre of the vessels, was also shown by an experiment with capsicum made at this period. A morsel of this substance having been placed upon the middle of a web in which the circulation was going on in perfect health and with unusual rapidity, the effect was great accumulation of corpuscles in two or three capillaries for a very short distance round the spot where the capsicum lay, unaccompanied by any change in the vascular dimensions.

Chloroform proved to be an agent which very readily induced stagnation when locally applied; and when it was administered in the usual way by inhalation for the purpose of performing experiments with warm water, it was found necessary to protect the webs carefully from its vapour, which otherwise produced the same appearances of congestion as the hot application. In one instance in which a small quantity of the liquid had been applied to the web, I saw the red corpuscles adhering to one another by their flat surfaces, in a manner not seen in the healthy condition, and exactly as described by Mr. WHARTON JONES to take place after the application of a strong solution of salt; but from the very slight tendency of chloroform to mix with water, it was impossible to believe that it had operated by way of exosmose, as was supposed by the authority just named to be the case with the saline solution*.

state of the webs is indicated to the naked eye by conspicuousness of the blood-vessels. In perfect health they are quite invisible without the microscope, and in all cases the appearance of any vessel as a distinct red streak is pretty sure indication of a certain amount of irritation.

* It was believed that the solution of salt abstracted water from the blood as it flowed through the capillaries, and that the liquor sanguinis being consequently inspissated, the red corpuscles assumed an abnormal tendency to aggregate together (see Guy's Hospital Reports, *loc. cit.* p. 40). This view has been more recently

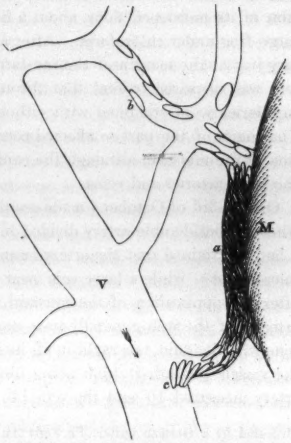
From the facts above mentioned, I became convinced that no satisfactory explanation had as yet been given of the obstruction experienced by the blood-corpuscles in the vessels of an inflamed part, and in September 1856 I again continued the investigation. Mustard being admitted to produce inflammation in any part of the human body to which it is applied, and also not appearing likely to act by way of exosmose, I selected it as a suitable irritant, and in order to study its effects accurately, placed a small portion of its moistened flour, about a line in diameter, upon the middle of the web of a large frog under chloroform. After a while, thinking that I saw stagnation in a capillary just at the margin of the mustard, I removed the latter with a camel's-hair brush, and was surprised to find that throughout the whole area on which it had lain, the capillaries were crammed with either stagnant or very slowly moving red corpuscles. The limits of the part so affected corresponded exactly with the extent of the application of the mustard, although the capillaries of adjoining parts were fed and drained by the same arteries and veins.

On the 3rd of October I made another similar experiment, selecting a part of the web where a considerable artery divided into small branches. Before applying the irritant, I had ascertained that the artery running through the area measured $6\frac{1}{2}°$ of an eyepiece micrometer*, while a large vein near it had a diameter of 12°. About half a minute after the application of the mustard, when I first looked through the microscope, the arteries of the web generally were much dilated, and the flow, which had before been somewhat languid, was rapid in all its capillaries. The opacity of the mustard prevented the vessels beneath it from being observed, but at a short distance from its edge the artery measured 10° and the vein 14°. In a few minutes the capillaries seen beneath

advocated by a German writer, Fr. Schuler of Glarus (Würzburg Verhandlungen, 1854), with a very elaborate series of difficult experiments. One of these, however, seems almost conclusive against his theory. Having injected a solution of prussiate of potash into the veins of a frog, he applied sulphate of iron to the webs, but found that very little blue colour was produced *until the epidermis of the web was scraped away*, when it showed itself distinctly. Considering how delicate a test prussian blue is of the presence of a mixture of the two salts, this result seems to show that there is far from being the same tendency to mutual interchange between the blood in the capillaries and fluids in contact with the surface of the web, as there would be if the intervening material were dead animal membrane of the same tenuity. Were the disposition to exosmosis and endosmosis such as is assumed in the above explanation of stasis from a solution of salt, it would be impossible for the animal to live long either in water or on dry earth. In the former case the blood would soon become diluted from imbibition, and in the latter inspissated from evaporation. But it is well known that frogs will live for months in water without food, and I have kept them for weeks together upon dry earth at a temperature of about 60° Fahr., and on removing from the webs a layer of dust and exfoliated epidermis, found the circulation perfectly healthy. Since the reading of this paper, I have seen a remarkable example of the power of the tissues of the webs to resist imbibition of water in an amputated limb with the blood retained in the vessels by a ligature. Though it was kept in wet lint, the blood in the vessels showed no indication of admixture of water till the tenth day, and then only in those parts of the web in which the arteries and pigment-cells gave evidence that they had lost their vitality. For further particulars regarding this experiment see pages 618 and 640 of this volume.

* The micrometer used on this occasion was differently graduated from that employed in the warm water experiments.

the extreme margin of the mustard, which was slightly transparent, were observed to be of crimson colour, in consequence of their containing closely-crammed corpuscles, some of which were still moving, while others were motionless. On the application of a higher power, the continuations of these capillaries immediately exterior to the mustard showed, many of them, red corpuscles sticking to their walls, and more or less obstructing the progress of the blood through them.



In the accompanying sketch of the vessels at one part, together with those corpuscles which were motionless in them, M represents the edge of the mustard, *a* a capillary partly overlaid by the mustard and crammed with stagnant corpuscles, *b* a capillary with red discs adhering to its internal surface, but still transmitting blood, while further from the mustard all the corpuscles were in motion, and consequently none appear in the drawing; *c* was a rouleau of red corpuscles projecting from a stagnant mass into the vein V, through which the blood was flowing rapidly; yet the rouleau, though its free end was moved to and fro by the current, was prevented by the mutual adhesiveness of its corpuscles from being broken up or detached. Thus it was evident that in the capillaries of the space covered by the mustard, the red corpuscles had an abnormal tendency to adhere both to the walls of the vessels and to one another, and were on this account accumulating and sticking within them, while almost immediately outside the mustard, the blood in the capillaries presented the same appearance as in other parts of the web. This effect was independent of changes in the calibre of the vessels, for any results of alteration in the size of the artery under the mustard must have been shared by the surrounding capillaries, which also derived their blood chiefly from it; and that the vessel was dilated to the same degree there as elsewhere, was shown by the fact, that its branches continued throughout the experiment to transmit full streams of blood after emerging from beneath the opaque mass. I also measured some capillaries by micrometer before the application of the mustard, and again after it had caused stagnation in them, and found that their dimensions remained the same*.

* The increased pressure upon the blood in the capillaries, resulting from obstruction to the progress of the corpuscles, leads to the distension of their elastic parietes up to a certain point, but, generally speaking, not further. In the present case, before the application of the mustard, the web, irritated probably by the vapour of the chloroform, was affected with a slight congestive tendency, far short of that which induces stagnation, but yet sufficient to give rise to full distension of the capillaries. When the web has been perfectly healthy to begin with, I have seen a marked increase of calibre in the capillaries on the occurrence of

The precise limitation of the effect produced upon the blood in these two experiments to the area covered by the mustard, showed that it was the result of a direct action of the irritant either upon the blood that flowed beneath it, or upon the tissues of the part of the web on which it lay, the blood being in the latter case affected secondarily. I made several experiments to determine whether the adhesiveness of the corpuscles in blood out of the body was increased by contact with, or vicinity to mustard, placing minute portions of it between plates of glass, and shedding a drop of blood from a frog, so that it might run in between the plates, and watching the result. I could, however, detect no evidence of such change in the corpuscles as I was seeking; whence I inferred that the blood had been only affected secondarily to the tissues in the two mustard experiments.

A careful study of the effects produced by the local application of chloroform to the web, confirmed in every respect the conclusions previously arrived at. If, while the eye of the observer is over the microscope, a minute drop of this liquid is placed with a camel's-hair brush upon the part in the field of view, it evaporates in perhaps two or three seconds; and if the web be dry, the time of its disappearance can be distinctly seen. Yet though it has so short a time to act, it produces so powerful an effect upon the part, that the red corpuscles immediately experience obstruction to their progress, and move too slowly in abnormal numbers through the capillaries, which perhaps become entirely clogged with them; the arteries meanwhile being in the state best adapted for easy transmission of the blood, *i. e.* full dilatation. In one such experiment I saw a few corpuscles sticking together in a capillary and moving with difficulty, from evident tendency to adhere to its parietes, their number gradually becoming augmented by the adhesion of others that followed, till the mass grew so large as to fill the vessel for some distance, when it finally stopped. In another case, the circulation being perfectly natural in the web, and the corpuscles moving on at slight intervals with no tendency to adhere, on a drop of chloroform being applied, I saw the very same corpuscles instantly become checked in their progress by sticking to each other and to the capillary walls, and move on slowly in masses with considerable intervals. Thus the nature of the effect produced upon the red corpuscles of the blood when chloroform is applied to the web is the same as that caused by mustard, viz. an abnormal degree of adhesiveness; whereas the earliest evidence of the direct action of chloroform on blood out of the body is the loss of the adhesive property of the red discs, as has been mentioned in Section I.* That the effect on the blood within the vessels of a part inflamed by chloroform is secondary to a change in the tissues is further proved by the circumstance, that abnormal accumulation of slowly moving corpuscles may last for hours together

stagnation in them. This I noticed particularly in a case in which caustic ammonia was the irritant employed. I would remark, however, that the eye is apt to be much deceived on this point unless the micrometer is used. Those vessels which are crammed with corpuscles, being of dark crimson colour, look at first sight larger than others, really of the same size, which contain the normal proportion of liquor sanguinis, and are therefore of pale tint.

* See p. 650.

without stagnation, as a consequence of the application of this irritant for an extremely brief period*. Long after all the blood which could possibly have been directly acted on by the chloroform has left the vessels, successive fresh portions continue to experience precisely similar changes in passing through the irritated area.

Heat produces similar effects. If the foot of a frog which is under the influence of chloroform be covered entirely with wet lint, except a small area of one of the webs, and a red-hot cautery iron be held for a few seconds about half an inch above the exposed part, inflammation will be excited in the area in proportion to the time of the action of the dry heat upon it; but on removal of the lint, the circulation will be found perfectly healthy in the surrounding parts. In the severer cases stagnation is universal in the exposed area, and the epidermis becomes eventually raised by the exudation of serum beneath it; but in milder instances nothing more than accumulation of slowly-moving corpuscles is produced, and I have observed this state of the part to continue for hours after the heat was applied. Here again the effect on the blood was obviously not due to the direct action of the heat upon it, but to some changes which it had effected in the tissues of the part on which it had acted.

Evidence of the same kind, but still more conclusive, is derived from the effects of mechanical irritation, where the agency is free from all objection of possible chemical action on the blood. The method adopted was that of compressing a small part of the middle of the web between little pads of soft material attached to the ends of the blades of a pair of surgical dressing forceps, by which the degree of pressure could be regulated at will. The results of this treatment were identical with those of heat, as just described. If the pressure was not made too severe, no mechanical obstruction was produced in the vessels, which nevertheless became loaded with slowly-moving or stagnant corpuscles; and on one occasion I observed the capillaries of an area which had been pinched, still transmitting languid streams of blood containing great excess of corpuscles several days after the injury had been inflicted, while in the surrounding parts the circulation continued perfectly healthy. Mechanical violence, like heat, chloroform and mustard, had effected an alteration in the tissues on which it operated, in consequence of which the blood in their vicinity assumed abnormal characters; and many other facts of similar nature might be added, if necessary, to show that this is the course always followed when accumulation of corpuscles in the vessels is induced by the action of irritants.

In discussions regarding the causes of the phenomena of inflammation seen in the frog's web, the great difficulty has hitherto been to account for the puzzling fact, that while the arteries still retain that state of enlarged calibre which is best adapted for easy transmission of the blood, its accelerated movement comes to give place to unnatural

* The gradual supervention of the effects of irritation upon the blood may be watched very conveniently by arranging a piece of lint soaked in chloroform, so that the vapour may play upon the web while the eye of the observer is over the microscope. If the chloroform be removed when the tendency to accumulation of corpuscles exists in a very slight degree, restoration to health will occur within a few minutes.

retardation and ultimate stagnation. Accordingly, various theories, mechanical, chemical and vital, have been proposed * to explain the transition from "determination of blood," as the condition of dilatation of the arteries with increased flow through the capillaries has been termed, to inflammatory congestion, as the accumulation of corpuscles in the vessels may perhaps be most fitly designated. But the second simple experiment with mustard, to which I would again direct the attention of the reader, proves in a very beautiful manner that these two results of irritation are totally distinct in nature and independent in cause. The dilatation of the arteries, it will be remembered, affected not only the part on which the mustard lay, but also all the rest of the web, showing that it was developed indirectly through the medium of the nervous system; whereas the accumulation of the blood-corpuscles in the vessels below the mustard was, as we have seen, the result of the direct action of the irritant upon the tissues. The arterial dilatation in the web generally led to no changes in the quality of the blood, which, though the experiment was continued for some hours, retained to the last its natural characters, just as would have been the case had the enlargement of the vessels depended on an operation performed upon the spinal cord. The accumulation of corpuscles, on the other hand, implied an alteration in the properties of the blood, viz. an abnormal adhesiveness in the red discs. Determination of blood is thus a purely functional phenomenon, and, like a blush upon the cheek, becomes obliterated after death by the *post-mortem* contractions of the vessels: inflammatory congestion, on the contrary, is the first evidence of organic lesion, and declares itself as distinctly in the dead as in the living, being the most important if not the only sign of the early stages of inflammation discoverable on dissection†, as for instance in the case of incipient meningitis mentioned in the Introduction to this paper.

Although determination of blood, as met with in the frog, is thus entirely independent of inflammatory congestion, yet it is of great interest with reference to human inflammation. Dilatation of the arteries is now generally admitted to be the result of the relaxation of their muscular fibres; and that it is a purely passive phenomenon, seems to be absolutely demonstrated by the fact which I have pointed out elsewhere‡, that after the vessels have been liberated from the control of the nervous system by removal of the spinal cord, they dilate fully if the heart continues to act sufficiently

* See 'Pathology and Practice of Medicine,' by W. P. ALISON, M.D., F.R.S.E.; 'Principles of Medicine,' by C. J. B. WILLIAMS, M.D., F.R.S.; 'Lectures on Surgical Pathology,' by JAMES PAGET, F.R.S.; 'Essay on the state of the Blood and the Blood-vessels in Inflammation,' by T. WHARTON JONES, F.R.S.; 'Guy's Hospital Reports,' vol. viii.; 'Clinical Lectures,' by J. H. BENNETT, M.D., F.R.S.E.; also Professor HENLE, as quoted by WHARTON JONES, *op. cit.*

† Since the reading of the paper, I have pointed out, that in consequence of the persistent fluidity of the blood which continues in the smaller vessels for days after death, the red corpuscles have time to gravitate into dependent parts, and thus give rise to that appearance of *post-mortem* congestion which more or less closely simulates to the naked eye what would have resulted from inflammation during life. See a paper by the author on spontaneous gangrene from arteritis, and the causes of coagulation of the blood in diseases of the blood-vessels, Edinb. Med. Journal, March 1858.

‡ See page 624 of this volume.

powerfully to distend them with blood, but not otherwise. Recent physiological discovery has shown that the arteries are not singular in being thrown into a state of muscular relaxation through irritation of the parts of the nervous system connected with them, the same being the case with the heart, the intestines, and apparently also with other hollow viscera. In a preliminary account of an inquiry into the functions of the visceral nerves, published in the 'Proceedings' of this Society*, I have given some notice of experiments which seem to show that in the case of the viscera alluded to, the state of relaxation under such circumstances is the result of the more energetic operation of nerves, which, when working more mildly, increase the muscular action of the same organs; the functions of the ganglia specially concerned in regulating the movements of the viscera being exalted by gentle stimulation on the part of the afferent nerves connected with them, but depressed by stronger excitation. In that paper the opinion was expressed, that the same explanation probably applies to the relaxation of the arteries, in consequence of nervous irritation; the general impression conveyed by the experiments with warm water above related being that arterial contraction was most apt to show itself when the degree of irritation was least, while dilatation was most marked when the stimulus was strongest. I have lately seen a striking illustration of this principle in a very simple experiment, which I was induced to make in consequence of reading a paper recently published by a French author, M. J. MAREY†. If a blunt-pointed instrument, such as the end of a pair of dissecting forceps, is drawn with gentle pressure along the back of the hand while it is in a state of moderate redness, the blood being driven out of the vessels, a pale streak results, which immediately disappears, in consequence of the return of the blood into the part. In a few seconds, however, a pale stripe, towards a quarter of an inch in breadth, becomes developed at each side of the line along which the instrument passed, that line having now assumed a red colour, if the pressure employed was at all forcible. This is M. MAREY's experiment; and there can be no doubt that his interpretation of the secondary paleness is correct, viz. that it depends on reflex arterial contraction. The red line, when it occurs, is evidently due to the direct action of the pressure upon the tissues, being, as M. MAREY correctly states, exactly of the same breadth as the instrument used. But I find that if the pressure be made with considerably greater force, so as to be positively painful, while the first white streak appears as before in consequence of the blood being dispelled from the vessels, the secondary paleness does not occur, but, on the contrary, a patch of the adjacent skin, extending for perhaps half an inch on each side, assumes abnormal redness, which lasts for a longer time than the paleness to which the other experiment gives rise. Here, the irritation being severe, the blood vessels are thrown through the medium of the

* Vol. ix. No. 32. The paper here referred to was written subsequently to the reading of the manuscript of this essay, and this was also the case with the remarks in the text on determination of blood.

† 'Recherches Hydrauliques sur la Circulation du Sang,' par M. J. MAREY. The separate copy of this paper, sent me by the author, does not contain any mention of the Journal in which it was published, so that I am unable to give proper reference to it.

nervous system into a state of muscular relaxation, instead of the contraction which is induced by a more gentle application of the same stimulus.

To return to the consideration of inflammatory congestion. Further light was thrown upon the condition of the blood in the vessels of an irritated part by a series of observations made when the circulation had been arrested by amputation of the limb, or by a ligature round the thigh. This field of inquiry was unexpectedly opened during the course of an experiment made with a view to ascertaining the effects produced by an irritant upon the pigmentary system independently of the circulation, as will be described in the next section. On the 13th of October 1856, a frog having been killed by destruction of the brain, the soft parts of one of the thighs were divided to the bone, and a small piece of mustard was placed on one of the webs of that foot. An hour afterwards, on removing the mustard, I saw to my great surprise that the small area on which it had lain was red to the naked eye, and that its capillaries, examined microscopically, contained abundance of closely-packed corpuscles, while in surrounding parts the blood was in the same condition as before the experiment, viz. of pretty healthy aspect. In other words, well-marked inflammatory congestion had been produced by the mustard, and I afterwards found that the same thing occurred in a limb completely severed from the body*.

This fact of course completely eliminated variations in the calibre of the vessels and consequent changes in the circulation from among the causes of congestion, and demonstrated conclusively its independence of the central organs of the nervous system. Further, it presented a very good opportunity for studying the state of the blood in healthy and inflamed parts, unaccompanied by the effects of rapid movement. In subsequent similar experiments, it was found that the corpuscles were not brought to the irritated area by anything that indicated a mutual attraction between the former and the latter, but were simply carried along by slight accidental movements of the blood, such as are caused by *post-mortem* contractions of the arteries, and instead of moving with facility, as in other parts, stuck when they arrived in the vessels of the area, in consequence of undue adhesiveness. The accumulation of the corpuscles was never to such an extent as in cases in which the heart was driving the blood through the part, but it affected the arterial and venous branches as well as the capillaries. Thus, if a large vein happened to run through the spot upon which the mustard was placed, it became in time choked with a crimson mass of corpuscles in that part of its extent which lay beneath the mustard; but immediately beyond, in both directions, the blood in it contained no more than the usual proportion of corpuscles, or sometimes considerably less; and these moved freely to and fro when the web was touched, whereas those

* Mr. Paget, to whom I mentioned this experiment, has informed me that the fact that stasis may be induced by application of irritant substances to the frog's foot after the arrest of the circulation by ligature of the thigh, had been previously discovered by Dr. H. Weber of Giessen (Müller's Archiv, 1852), and that Schuler of Glarus had afterwards ascertained that the same thing occurs in an amputated limb (*vide* Würzburg Verhandlungen, 1854).

within the area remained fixed. This proved that the cause of the accumulation of the corpuscles did not reside specially in the capillaries, and also showed distinctly that it could not be explained by mere abnormal adhesiveness of the vascular parietes, which was, I understand, the view entertained by the late Dr. MARSHALL HALL; for supposing the walls of the vessels to experience such a change, which seems by no means improbable, this could only lead to encrusting of the lining membrane of such a vein with adhering corpuscles, and not to the occupation of its whole calibre by them, as took place in these cases, unless the corpuscles were themselves also abnormally adhesive.

Another important fact which was brought out by this class of experiments is, that mere quiescence of the blood in the vessels of a healthy part fails to induce aggregation of the red corpuscles, such as occurs in blood outside the body. In the parts which had not been subjected to irritation, the corpuscles exhibited no trace of adhesiveness; and though completely at rest, they were nowhere to be seen grouped together, surface to surface, although in the larger vessels there was abundant space for the occurrence of this phenomenon, which invariably presents itself in freshly drawn frog's blood examined between plates of glass in a sufficiently thick film. On one occasion, when examining the tissues of the web of a frog under chloroform, the limb being kept steady by a string tied tightly round the thigh, so as completely to arrest the circulation, I was particularly struck with the total absence of adhesiveness in the red corpuscles; so much so, that, as the foot had been kept moist without circulation for about three hours, I suspected that it must have imbibed water, which, when mixed with blood outside the body, destroys altogether the adhesiveness of the red corpuscles. This, however, proved to be a mistake; for, having occasion to administer more chloroform, I applied it on a piece of lint of considerable size without taking the usual precaution of protecting the foot from the vapour, and left it so for about a quarter of an hour. On re-examination of the web, the red corpuscles were found to possess much mutual adhesiveness, and in the larger vessels were grouped together into masses, with considerable spaces of clear liquor sanguinis, just as in the best-marked forms of aggregation in frog's blood outside the body. One of these masses was drawn by camera lucida, and is represented in the sketch at page 648, along with the outline of the vessel in which it lay. I afterwards purposely induced a similar change in the blood within the vessels of an amputated limb by means of mustard*. Having ascertained that the red corpuscles, though they had been long at rest, were perfectly free from the slightest tendency to aggregation, I suspended, at a little distance from the web, a piece of lint smeared with freshly prepared mustard, so that the pungent vapour of the volatile oil might play upon it; and left it so for about a quarter of an hour, when I found the red discs aggregated, as usually seen in frog's blood outside the body. I then shed some blood from the other leg between two plates of glass, and on carefully sketching and comparing the groups of corpuscles in this specimen and those within the vessels of the irritated webs, found that

* This experiment was performed subsequently to the reading of the paper.

their characters were precisely similar*. These are examples of what very numerous observations have tended to establish, namely, that on the one hand the red corpuscles in the vessels of a perfectly healthy part are free from adhesiveness; and on the other hand, the adhesiveness which they acquire in inflammatory congestion, though varying in proportion to the degree of irritation, is never greater than occurs in the blood of a healthy part when withdrawn from the body.

These conclusions, if correct, represent cardinal truths, both in physiology and pathology, implying relations of the tissues to the blood both in health and in disease, such as have never before been demonstrated, or, I believe, even suspected. I was therefore anxious to submit them to further test, particularly as it is by no means easy to estimate the precise degree of adhesiveness possessed by the red corpuscles within the vessels; and it occurred to me that one means of doing this would be to compare specimens of blood shed from inflamed and healthy parts of the same individual; for if my deductions were sound, the adhesiveness of the red corpuscles ought to be neither more nor less in the one case than in the other.

With this view I made the following experiments. Having carefully examined the blood of a large frog, drawn from a subcutaneous vein of the abdomen, so as to become quite familiar with the appearance of its corpuscles, I applied mustard to the whole surface of one foot till inflammatory congestion had been fully developed in it, and then, amputating both feet at the ankle-joint, squeezed out blood from each upon a glass plate, and carefully examined both specimens, without being able to detect the slightest difference between them. The other experiments with this object were performed on the human subject. In one of these I applied a portion of moistened mustard to the dorsal aspect of the last phalanx of one of my fingers, and retained it there for five hours, with the exception of occasional removal for the purpose of drawing blood for examination. By the conclusion of the time mentioned, the skin on which the mustard had been placed was in a very decided state of inflammation, being red, swollen and painful, and the redness at one spot disappearing imperfectly on pressure, and returning languidly after its removal. A very minute drop of blood drawn with a fine needle from the surface of the most inflamed part was then compared with a drop of similar size from another finger, but no difference could be detected between them, nor had any been observed in previous similar comparisons. On another occasion, a friend of mine suffering from intense inflammation of the back of the hand, in consequence of the irritation of offensive pus, permitted me to take blood with a needle from the most severely affected part, and also from one of the fingers, which was healthy. I compared drops from the two sources several times very carefully with each other by means of the micro-

* In performing experiments upon a foot in which the circulation has been arrested, it is important to guard against a deception apt to arise from the direct action of an irritant upon the blood in the vessels. Thus, if a drop of chloroform of considerable size be applied to a web under those circumstances, it will soak in and produce its chemical effects upon the blood, the earliest of which is complete abolition of adhesiveness in the corpuscles.

scope, but could discover no difference between them in the adhesiveness of their corpuscles; as indicated by the time of formation of the rouleaux, their mode of grouping, and the tenacity with which the discs composing them adhered when they were stretched. The results of these experiments appear decidedly confirmatory of the conclusion with reference to which they were instituted.

No mention has been hitherto made of the appearance presented by the colourless corpuscles in an irritated part. It is well known that their numbers, in proportion to the red ones, vary very much in different frogs, and it so happened that in the two on which the first mustard experiments were performed they showed themselves but little; nor are they at all conspicuous when the circulation has been arrested by ligature; but in most cases in which irritation is applied to the web while the blood is circulating through it, one of the earliest abnormal appearances is that of white corpuscles adhering in large numbers to the walls of arteries, capillaries and veins, as first described and accurately figured by Dr. WILLIAMS*. This remarkable phenomenon, though of itself clear proof of an alteration in the properties of the blood in an irritated part, has, strangely enough, attracted little attention from other observers. It is evidently analogous to the change which the red discs experience under similar circumstances. I find that the account commonly given of the white corpuscles in circulation in the vessels of the frog's web, viz. that they may be seen rolling slowly along the walls of the arteries and veins, and sometimes sticking to them, though intended to apply to the state of health†, really describes a condition of a slight amount of irritation, such as is exceedingly apt to be induced by a variety of causes‡. In perfect health the colourless corpuscles are as free from adhesiveness within the vessels as the red discs, but like them assume that property in a degree proportionate to the amount of irritation to which the part has been subjected. When the irritation has been very slight, the white corpuscles, which are susceptible of much greater adhesiveness than the red (as we learn from examining blood outside the body§), acquire some tendency to stick to the vascular parietes, while the red discs still move on in a manner generally regarded as consistent with health, though really lagging slightly behind the liquor sanguinis, and con-

* Vide *op. cit.*

† Mr. WHARTON JONES, in describing the healthy circulation in the bat's wing, speaks of the colourless corpuscles as "rolling or sliding sluggishly along the walls of the vessels," "both in arteries and veins." He also describes, in the following passage, increased adhesiveness as resulting from irritation. "Towards the end of a protracted sitting, after the web had been much irritated, I have seen, in the venous radicles especially, colourless corpuscles accumulated in great numbers, as we so often see them in the frog." But no stress is laid on this fact as bearing upon the nature of inflammation (see "Observations on the state of the Blood and the Blood-vessels in Inflammation," by T. WHARTON JONES, F.R.S., Medico-Chirurgical Transactions, vol. xxxvi. 1853). Dr. WILLIAMS, supposing that the white corpuscles were always adhesive within the vessels in health, was led to attribute their abnormal accumulation in an irritated part to local fresh formation of those bodies. Vide *op. cit.*

‡ It has been mentioned in the note to p. 660, that this effect is peculiarly liable to be produced in consequence of the vicinity of the warm hand.

§ See page 649.

sequently presenting themselves in somewhat abnormal proportion. I have often observed the complete absence of adhesiveness of the white corpuscles within the vessels in health, and have also watched them gradually assume a tendency to adhere, in consequence of repeated mild applications of chloroform to a web in which they previously exhibited no such disposition whatever. As the irritation increases, the vessels become crusted with them often to a remarkable degree, and occasionally large, colourless, agglomerated masses of them, just such as are seen in blood drawn from the body, may be observed to roll along the large veins among the slowly moving and very numerous red discs. I once watched the formation of one of these masses* as a delta-like accumulation at the place where a considerable venous branch opened into a main trunk, the calibre of which was nearly entirely occupied by it before it was swept away by the current. As a general rule, the white corpuscles when adhering do not arrest the progress of the red ones, which are often seen to pass through very small intervals among the colourless masses; not unfrequently, however, red corpuscles are stopped in their course and adhere among the white ones, and sometimes, especially in young frogs, capillaries become obstructed throughout their entire length by white corpuscles alone, and when this is the case, they are apt to escape notice from the inconspicuous character of their contents.

The adhesiveness of the white corpuscles, as of the red ones, is limited to the part irritated. A very good example of this presented itself on one occasion when a minute drop of chloroform was applied to a small part of a healthy web so as to induce full dilatation of the arteries and great excess of corpuscles, but without absolute stagnation. It happened that the part affected was supplied with blood by the branches coming from one side of a principal artery; the main trunk being seated just about the limit between the irritated area and the healthy region, the adjacent part of which received supply from the branches of the vessel on the other side. The latter showed no appearance of adhering white corpuscles, nor did the capillaries which were fed by them; but those of the irritated part, though springing from the same trunk, were remarkably encrusted with them from their origin to their minutest ramifications within the area, while the capillaries and veins in the same part were similarly affected. This striking appearance continued for hours after the chloroform had been applied, successive fully formed white corpuscles adhering as they flowed in from the trunk, being evidently affected secondarily to the change induced by the chloroform in the tissues of the web.

Thus the affection of the white corpuscles of the blood in an irritated part is in all respects strictly parallel to that of the red discs, while the greater adhesiveness of which the former are capable, renders the facts regarding them more obvious and unmistakeable.

Being desirous to verify the results derived from the frog by observations upon mammalia, in which the aggregation of the red corpuscles assumes a much more striking appearance, I examined the wings of two small bats. In the first specimen, the corpuscles, both red and white, exhibited decided adhesiveness within the vessels, the web being apparently in a state of irritation from injuries which the animal had sustained. In the other there was also some adhesiveness in the part that first met my eye, the red discs tend-

* This observation was made subsequently to the reading of the paper.

ing to aggregate into rouleaux, and giving a lumpy aspect to the somewhat dark streams in the larger vessels: but turning to another place, I found the blood there of pale tint and perfectly homogeneous aspect; nor could I detect by a careful search any evidence of a tendency on the part of the white corpuscles to stick to the vascular parietes. It happened that there was complete absence of flow in one artery and concomitant vein of considerable size, yet not a rouleau was to be seen either in them or in any of their branches. On the contrary, the red discs lay at about equal distances from each other, uniformly distributed throughout the calibre of the vessels; and this state of things remained unchanged during about a quarter of an hour, in which I continued to observe them in their perfectly quiescent condition. On examination of some blood from the heart of this bat shortly after, the red corpuscles exhibited a very remarkable degree of adhesiveness, such as I had never seen in human blood*, presenting a glaring contrast with their state within the vessels†.

Thus we may, I think, regard it as fully established, that, in mammalia as well as in amphibia, both the red discs and the colourless globules of the blood are completely free from adhesiveness within the vessels of a perfectly healthy part, but that when the tissues have suffered from irritation, both kinds of corpuscles assume, in proportion to the severity of the affection, a degree of that tendency to stick to one another and to neighbouring objects which they possess when withdrawn from the body, and consequently experience obstruction to their progress through the minute vessels.

And here I cannot avoid remarking, that this principle explains, if it does not altogether reconcile, the discordant opinions of physiologists regarding the causes of the circulation. It shows that while there is, as we have before seen‡, strong ground for agreeing with those who hold that the flow of the blood is due simply to the contractions of the heart, aided, in animals with valved veins, by the actions of the muscles, the respiratory movements, and, in the case of the bat's wing, by rhythmical venous contractions; yet there is also much truth in the view of those who maintain that the tissues of a part, independently of any change of calibre in the vessels, exercise a great influence upon the progress of the blood through the capillaries. For though the tissues do not, as has been hitherto supposed by the latter class of authorities, actively promote the circulation, yet their healthy condition is none the less necessary to it, being essential to the fitness of the blood for transmission by the heart through the minute vessels.

* The remarkable adhesiveness of the red corpuscles of the blood of this bat, when withdrawn from the body, has been particularly described in Section I., page 649.

† Mr. WHARTON JONES, in the paper before referred to, describes the red discs as aggregating within the vessels of the healthy bat's wing, when their movement is arrested from any cause, in the same manner as in blood removed from the body. *Vide* Med.-Chir. Trans. *loc. cit.* I suspect that the pressure of the plate of thin glass employed in order to bring the necessarily high powers of the microscope to bear upon the object is apt to irritate the web and give rise to a degree of congestion, characterized by a tendency to aggregation on the part of the red discs and adhesion of the colourless corpuscles to the walls of the vessels. I have observed that results of irritation have shown themselves in the web of the frog when I have used a plate of thin glass in the same manner as with the bat, for the purpose of applying a high power to the pigmentary tissue.

‡ See page 654.

It is an interesting question, whether the freedom of the corpuscles from adhesiveness in health is due to some active operation of the tissues upon the vital fluid, or whether their adhesiveness in an inflamed part or outside the body is the result of a prejudicial influence exerted upon the blood by the irritated tissues, or by the objects of the external world with which it comes in contact when shed. The fact that the non-adhesiveness of the corpuscles within the vessels continues in an amputated limb, shows that it is independent of the central organs of the nervous system, and probably too of any nutritive actions going on in the tissues. Also, if the latter were concerned in its production, we should expect to find the corpuscles adhesive in the large arteries and veins of the webs, since it is doubtless chiefly in the capillaries that the mutual interchanges take place between the blood and the solid elements of the body. It may be difficult to obtain further evidence upon this point, but some light may be thrown upon it by the consideration of the causes of the coagulation of the blood, which seems to be a closely allied subject.

I have shown elsewhere*, that in mammalia, as well as in amphibia, the blood remains fluid for days in the veins of an amputated healthy limb, though retaining its property of coagulating when shed†. Its fluidity within the vessels is unaffected by free admixture of the atmosphere with it. For example, seven hours after injecting air into the veins of an amputated sheep's foot, I found the frothy mixture contained in the vessels still quite fluid; and the blood which formed the bubbles, coagulated when shed. Again, a human leg having been amputated above the knee, I pressed out the blood from about an inch of the open mouth of the popliteal vein, and covered the raw surface lightly with a damp cloth, so as to guard against drying of the blood, or of the walls of the vessel in contact with it. After the lapse of twenty-four hours, the vessel was still patulous; but the blood, though it had been so long freely exposed to the influence of the air, continued perfectly fluid. Further, if a vein in an amputated sheep's foot is simply wounded, no clot forms except at the seat of wound. If, however, a portion of any ordinary solid matter, such as a fragment of glass, a bit of clean wax, a hair, a needle, or a piece of fine silver wire, be introduced into such a vein, a deposit of fibrine takes place after some minutes upon the foreign body‡, followed by coagulation of the blood in that particular part of the vessel; the coagulum, however, never adhering

* See a paper by the author "On spontaneous Gangrene from Arteritis, and the Causes of the Coagulation of the Blood in Diseases of the Blood-vessels," Edinburgh Medical Journal, March 1858. The observations there recorded, and also the others mentioned in the text with regard to coagulation, have been made since the reading of the original manuscript.

† The blood coagulates more slowly the later it is examined after death or amputation, and finally becomes altogether incapable of the process. The time when this occurs differs in different cases. Thus, in the foot of the sheep I have seen coagulation take place, though slowly, on the sixth day; but in the human subject on one occasion I found the blood remain permanently fluid when shed within forty-eight hours of death, though in another instance at the same period a soft clot formed in about half an hour.

‡ These facts, ascertained in November 1858, have considerably modified the views expressed in the paper above referred to.

to the vein, except at the lips of the wound*. This shows that an ordinary solid possesses an attraction for the particles of the fibrine, such as is not exercised by the walls of the vessels; or, in other words, that the vascular parietes differ from all ordinary solid substances in being destitute of attraction for that element of the liquor sanguinis.

The blood-vessels are not the only constituents of the animal body which have these remarkable relations to the blood. If the integument of a sheep's foot be partially reflected, and one of the subcutaneous veins immediately wounded, so as to let some blood run into the angle between the skin and the rest of the limb, before any drying of the tissues has occurred, care being taken that no hairs or other solid matters have been introduced, this blood will remain in whole or in part fluid for half an hour or more; whereas, if blood from the same vessel be placed in contact with any ordinary solid, whether on the foot or elsewhere, it will coagulate in perhaps five minutes†. This is sufficient proof that the subcutaneous cellular tissue resembles the lining membrane of the vessels in its conduct towards the blood. The long time during which blood

* From what has been stated in the text, it is evident that the ammonia theory of Dr. B. W. RICHARDSON does not account for the fluidity or coagulation of the blood within the vessels. But the facts mentioned by that gentleman in the valuable essay which has gained the last ASTLEY COOPER prize, and also my own experience [see the paper before referred to], have convinced me that a certain amount of the volatile alkali does exist in freshly-drawn blood, and that it has the effect of retarding the process of coagulation. This principle must be borne in mind in all experiments upon this subject, in order to understand circumstances which would otherwise be inexplicable. Thus, if the foot of a sheep be obtained with the blood retained in the vessels by a bandage applied before the death of the animal, and, after reflection of the skin, a needle be introduced into a vein by a free opening made by the scissors, a deposit of fibrine will be found upon it in perhaps five minutes; but if the needle be pushed through the coats of such a vein, so as to introduce it without previous wound of the vessel, and allow little opportunity for escape of ammonia, the deposit will not take place for a quarter of an hour or more. Again, the blood obtained by wounding a vein immediately after reflecting the skin, within the first few hours after the death of the animal, takes a much longer time to coagulate the blood shed from the same vessel after the lapse of half an hour or so; doubtless in consequence of escape of ammonia having occurred in the interval. This circumstance seems to prove that the ammonia is free in the blood in its normal condition within the vessels, and not merely liberated during the process of coagulation; for it is to be remembered that the mere wounding of a vein in no way interferes with the fluidity of the blood in it, except at the wound.

† After the blood has lain for some time in the angle between the skin and the limb, it coagulates, if removed from it, much more rapidly than blood freshly shed from a vessel. Thus, in one case, blood let out from a vein was part of it placed at once on a glass plate, and part allowed to run into the angle between the skin and limb. That on the glass plate was not completely coagulated for ten minutes; but that in the other situation, having been left for twenty minutes, and then transferred to the plate, was a consistent clot within six seconds, indeed as soon as I could examine it. This fact seems to me to throw great light upon the subject of coagulation. The sudden transition from perfect fluidity to a coagulum can only be explained, I conceive, on the hypothesis that the ammonia had almost all escaped while the blood lay in the angle; yet this escape had not caused coagulation. Hence it seems to follow, that ammonia is in no way essential to the fluidity of the blood while it is surrounded by healthy tissues. Another point, which the simple experiments upon the sheep's foot show clearly, is that a certain amount of ammonia in the blood will retard without preventing the deposit of fibrine upon a needle or other ordinary solid introduced into the vessels; and it appears very doubtful whether healthy blood ever contains sufficient ammonia to prevent such an occurrence.

has been observed to remain fluid but coagulable in the tunica vaginalis, seems to show that serous membranes are similarly circumstanced; and it appears probable that the same may be the case with other tissues.

But though some of the facts above mentioned furnish clear evidence that ordinary solid matter induces coagulation by an attractive agency, it by no means follows that the tissues are necessarily merely neutral in their conduct towards the blood in this matter. It is quite possible that they may exert an active influence upon it, in consequence of which the particles of fibrine may experience a mutual repulsion, in the same way as would seem to be the case with the pigment-granules of the chromatophorous cells of the frog during the process of diffusion*. Indeed some such hypothesis seems almost necessary in order to explain the remarkable fact, that the blood coagulates within a few hours of death in the cavities of the heart and great venous trunks, though it retains its fluidity for days in the smaller vessels. Thus in the human subject twenty-four hours after death I have found clots in the heart and larger veins, including the upper parts of the axillary and femoral trunks, but fluid blood in the lower parts of those vessels and all their branches in the limbs. It seemed possible at first that this difference might depend on the position of the great vessels in the thorax and abdomen, where decomposition begins earlier than in the limbs. But this proved not to be the case; for in a horse twelve hours after it had been killed, I found the blood fluid in the intercostal and small cardiac veins, though coagulated in the vena cava and the coronary vein of the heart, which is in that animal of very large size. There being no reason to suppose the walls of the larger vessels differently constituted from those of the smaller ones, or more liable to undergo *post mortem* changes, the natural interpretation of these facts seems to be that the blood has, even within the body, a certain tendency to coagulation, counteracted by an influence exerted upon it by the containing tissues, which, operating to less advantage the larger the mass of the fluid acted on, fail, at least after death, to prevent it from following its natural course in vessels of a certain magnitude. Again, if we suppose that the tissues are merely passive with regard to the blood, it seems difficult to understand the rapid solidification of a large quantity shed into a cup. For we have seen that mere exposure to the atmosphere will not account for the fact; while at the same time the experiments upon the sheep's foot indicate that an ordinary solid has but a very limited range of operation upon the surrounding blood†, and that the clot which it induces does not propagate itself to more distant parts; so that the central portions of such a mass of blood should remain fluid, unless we admit that, when

* See p. 634 of this volume.

† I find that if a needle is introduced into a vessel and removed after the expiration of about two minutes, before any deposit of fibrine has yet occurred upon it, a certain amount of coagulation nevertheless takes place afterwards in that particular part of the vessel in which the needle had lain. This is a curious circumstance, indicating that an impression leading to coagulation is produced upon the blood by contact with an ordinary solid for a shorter time than causes, during its presence, any visible solidification. The clot, however, is very slow in forming and very incomplete, so that such cases cannot be compared with the perfect and rapid coagulation of a large mass of blood outside the body. Indeed, when blood is drawn into a large cup, a great deal of it never touches the side (the ordinary solid) even for an instant.

shed from the vessels, it is liberated from an influence which previously kept in check a spontaneous proneness to coagulation. Hence it seems likely that a foreign solid introduced into a vein acts not by creating a disposition to aggregate on the part of the fibrine, but by increasing a pre-existing tendency to it (as a thread induces the crystallization of sugar-candy), exalting the mutual attraction of its particles to a degree which overcomes a counteracting agency on the part of the tissues.

Further inquiry will, in all probability, throw clearer light upon this subject, but in the meantime the facts already known furnish to the unaided senses indisputable proof of the fundamental principle to which we were led by microscopical observation, viz. that the tissues through which the blood flows have, when healthy, special relations to the vital fluid, by virtue of which it is maintained in a fit state for transmission through the vessels. Further, the differences of adhesiveness in the corpuscles according as the blood is surrounded by healthy tissues or ordinary matter, can now be no longer matter of surprise, knowing as we do the alterations which take place in the chemical condition of the liquor sanguinis in consequence of such changes of circumstances, and also the great effect produced upon the adhesiveness of the red discs in blood outside the body by slight variations in the quality of the plasma *.

The freedom from attraction for the fibrine, if not the actual repulsion of it, on the part of the walls of healthy blood-vessels, seems to explain the well-known fact in pathology, that when healthy capillaries are subjected to abnormal pressure in consequence of venous obstruction, the fluid squeezed through their parietes consists almost exclusively of serum; the fibrine being apparently excluded from their pores as liquid mercury is from those of flannel, or any other texture composed of a material destitute of attraction for it.

From the speedy coagulation of lymph effused into the interstices of inflamed organs or upon inflamed serous surfaces, compared with the length of time that blood has been known to remain fluid after being poured out into such situations in a state of health, and also from the deposition of fibrine which occurs at an early period upon the lining membrane of the vessels in arteritis or phlebitis, whether in the limited inflammation which results from the application of a ligature, or in the more extensive affection which is apt to occur spontaneously, it would appear that the liquor sanguinis, like the corpuscles, tends to comport itself near inflamed tissues as if in the vicinity of ordinary solid substances. It is true that coagulation is not observed to occur in the vessels of the frog's web after the application of irritants; but this is accounted for by the length of time required for the occurrence of the process within the vessels, the liquor sanguinis passing on into healthy regions, leaving the adhesive corpuscles behind it. Adhesiveness of corpuscles may, however, come on in circumstances which admit of permanent fluidity of the blood. Thus if a cat be killed without hemorrhage, and one of the jugular veins be exposed and tied in two places, and the animal be then suspended by the head so that the vein may be vertical in position, the upper part of the venous compartment included between the ligatures will within a very few minutes become colourless in consequence of rapid subsidence of the red corpuscles, implying that they are already closely

* See Section I. p. 650.

aggregated, although, if the skin be carefully replaced so as to prevent drying of the tissues, the blood will remain fluid in that part of the vein for many hours. Whether the adhesiveness of the corpuscles in this case depend on a *post mortem* change in the vessels, or whether it is merely the result of the large size of the vein preventing the tissues from acting effectually on the blood, remains to be determined; but such a fact seems to prove that a higher grade of vital activity, so to speak, is required to prevent adhesiveness of corpuscles than to maintain the fluidity of the blood. Hence it is probable that, even if the blood were at rest in the vessels of a part, a stronger degree of irritation would be required in order to determine coagulation than would suffice to induce adhesiveness of the corpuscles, which seems to be a more sensitive test of a deviation of the tissues from the standard of health. I have however ascertained, by experiments upon the amputated sheep's foot, that if caustic ammonia is applied freely to a part of a vein after pressing the blood out of it, and the blood allowed to return when the ammoniacal odour has passed off, coagulation takes place in the portion of the vessel which has been so treated, although the chemical action of ammonia, if any of it remained in the tissues, would tend to prevent or check coagulation*. I have also found a similar local clot form, though more slowly, after merely pinching a piece of a vein.

FRANKLIN INSTITUTE LIBRARY

The principal results obtained in this section may be summed up as follows:—

The effects produced upon the circulation by the application of an irritant to a vascular part are twofold, consequent upon two primary changes in the tissues, which, though often concomitant, are entirely independent both in nature and mode of production. One of these is dilatation of the arteries (commonly preceded by a brief period of contraction), giving rise, in proportion to the increase of calibre, to more free flow through the capillaries, the blood remaining unaffected, except in the rate of its progress. This purely functional phenomenon is developed indirectly through the medium of the nervous system, being not limited to the part acted on by the irritant, but implicating a surrounding area of greater or less extent. The other change is the result of the direct operation of the irritating agent upon the tissues, which experience some alteration, in consequence of which the blood in their vicinity becomes impaired, losing the properties which characterise it while within a healthy part, and which render it fit for transmission through the vessels, and assuming those which it exhibits when removed from the body and placed in contact with ordinary solid matter. The first indication of this disorder of the vital fluid is, that its corpuscles, both red and white, acquire some degree of adhesiveness, which makes them prone to stick to one another and to the vascular parietes, and, lagging behind the liquor sanguinis, to accumulate in abnormal numbers in the minute vessels. This adhesiveness may exist, in proportion to the severity of the affection, in any degree, from that which merely gives rise to a very slight preponderance of the corpuscular elements of the blood in the part, up to that which induces complete obstruction of the capillaries; and when the irritation has been very severe, the liquor sanguinis also shows signs of participation in the lesion by a tendency to solidification of the fibrine.

* See the paper "On Spontaneous Gangrene," &c., before referred to.

SECTION IV.

On the Effects of Irritants upon the Tissues.

The object of the present section is to inquire into the nature of that primary change which we have seen to be produced in the tissues by the direct action of irritants upon them.

The conclusion already arrived at, that blood flowing through an irritated part approaches more and more nearly, in proportion to the intensity of the affection, the condition which it assumes when separated from the living body, naturally leads us to infer that the tissues concerned are in some degree approximated to the state of ordinary matter, or, in other words, have suffered a diminution of power to discharge the offices peculiar to them as components of the healthy animal frame.

This inference is strongly supported by considering what common effect is likely to be produced upon the tissues of the frog's web by all the various agents known to cause inflammatory congestion. To take first the case of mechanical violence. A forcible pinch of the delicate web seems likely, *a priori*, to impair its powers; for if the lesion be sufficiently severe, complete death of the part will result. An elevated temperature proves equally destructive if carried far enough; and its operation to a degree just short of this, while it produces congestion, can hardly fail to cause diminished vigour in the tissues. So also powerful chemical agents, if used cautiously, give rise to inflammation; but if otherwise, kill the part they act on. Even the pungent irritants which do not exert much chemical action, seem to benumb the energies of the spot to which they are applied. Thus a morsel of capsicum placed on the tip of the tongue speedily produces numbness there, and a piece of mustard lying on the finger for an hour or two dulls the sensibility of the skin. Chloroform, too, while it very readily induces stagnation followed by vesication in the frog's web, is an agent which appears likely to benumb the vital energies. If a small frog be put into a bottle of water highly charged with carbonic acid, and removed from it some time after all motion of the limbs has ceased, it will be found that, though the heart is still beating, the blood-vessels of the webs are loaded with stagnant corpuscles. After a while, however, resolution will take place, and some time later the animal will regain its consciousness. Here it appears probable that the carbonic acid, poisoning the web as well as the brain, paralyses for a time the functional activity of both; and that the return of the circulation, like the recovery of the cerebral functions, depends on a restoration of the dormant faculties of the affected tissues.

Perhaps the most instructive case is that of the galvanic shock, which the following circumstances first showed me to be capable of causing inflammatory congestion. Being desirous of ascertaining the effects of galvanism upon the cutaneous pigmentary system, I applied the poles of a battery in rather powerful action to the skin of the head of a frog, when, the shock affecting the brain, the animal was stunned and lay perfectly motionless. This state of things being favourable for pursuing my inquiry by aid of the microscope, I drew down one of the passive limbs, and having placed the foot under

the instrument, arranged the fine platinum wire extremities of the poles at a short distance from one another at opposite sides of one of the webs, so that the current might pass through a part in the field of view, the circulation meanwhile remaining healthy. I now completed the circuit of the battery, when the leg became instantly drawn up by reflex action; yet on re-examination of the web, I found that, momentary as the shock had been, the part through which it had passed had become affected with intense inflammatory congestion, gradually shading off towards the healthy condition, which existed at a little distance. After about a quarter of an hour resolution of the confused mass of stagnant corpuscles occurred, and shortly after this the creature regained the power of voluntary motion. I afterwards repeated the experiment, both upon the same animal and upon another specimen, and always with the same results; and I particularly observed in one case that the white corpuscles were affected with great adhesiveness in the congested region.

With regard to the manner in which the abnormal condition of the blood was brought about in these cases, it has been already mentioned in Section I. that the galvanic current produces no increase of the adhesiveness of the red corpuscles of blood outside the body; but after what has been stated in the last Section, the reader will see no reason to think such an effect likely. It may, however, seem not improbable that the galvanic shock might, by its direct action upon the blood within the vessels, reduce it to the same condition as if removed from the body. But that this was not really the cause of the congestion, was clear from the fact that in the parts less intensely affected, where the corpuscles still moved slowly though possessed of considerable adhesiveness, the same condition continued long after all the blood which was in the vessels when the shock was transmitted had passed away. In this case therefore, as in all the others which we have considered, the blood was affected secondarily to the tissues. This being established, the natural interpretation of these experiments appears to be, that the portion of the web affected was, as it were, stunned by the shock, and its functions suspended like those of the brain; the resolution of the inflammation, like the return of volition, depending on recovery of function on the part of the tissues concerned.

From such considerations as these, it appears that all those agents which produce inflammatory congestion when applied to the web, though differing widely in their nature, agree in having a tendency to inflict lesion upon the tissues and impair their functional activity.

But powerful as are the arguments thus obtained by inference, it is very desirable to confirm them by direct observation, and it fortunately happens that the cutaneous pigmentary system of the frog is a tissue which discharges functions very apparent to the eye, so that it is easy to trace their modifications under the influence of irritation.

In the first experiment with mustard described in the last section (performed September 29th, 1856), the space on which the irritant had acted presented a very striking difference from the rest of the web in the appearance of the pigment, which in healthy parts was in the form of small roundish black dots; while in the mustard area, and accurately corresponding to the extent of stagnation in the capillaries, each spot was extended to a stellate figure.

I thus became for the first time aware that the pigment is capable of variations, and my attention having been directed to the subject, I soon found that similar changes occur spontaneously, and give rise to alterations in the colour of the skin, which is paler in proportion as the colouring matter is more completely collected into round spots. For some weeks I supposed myself to have been the first discoverer of this curious fact, till I was referred by Dr. SHARPEY to the recent labours of the Germans on the subject. They, however, as I afterwards found, had taken an entirely erroneous view of the phenomenon, attributing the round form of the masses of pigment to contraction of the branching offsets of stellate cells; whereas it turned out that the chromatophorous cells do not alter in form, but that the colourless fluid and dark molecules which constitute their contents are capable of remarkable variations in relative distribution, the molecules being sometimes all congregated in the central parts of the cells, the offsets containing merely invisible fluid, while at other times the colouring particles are diffused throughout their complicated and delicate branches; and between these extremes any intermediate condition may be assumed. It further appeared that concentration of pigment takes place in obedience to nervous influence, while diffusion, though also an active vital process, tends to occur when the pigment-cells are liberated from the action of the nerves. But for further particulars on this subject, I beg to refer the reader to the immediately preceding paper in this volume.

The contrast between the pigment in the area on which the mustard had acted and that of surrounding parts in the case last alluded to, at once struck me as probably the result of a direct action exercised upon the tissues by the irritant. It seemed possible, however, that it might be a secondary effect of the state of the blood in the congested vessels; and in order to ascertain which was the truth, I performed, on the 14th of October, the following experiment:—

Having cut out a piece of the web of a healthy frog, I placed a small portion of mustard upon its centre when all the blood had escaped from it. After a while the spots of pigment seen through the thin margin of the mustard, presented a stellate form, while in the rest of the piece they were still of a rounded figure. Hence it was clear that the change in the disposition of the pigment was the result of the direct action of the mustard upon the tissues of the web.

A new field of investigation was thus opened before me, promising to throw great light upon the nature of inflammation.

To explain the effects of irritants upon the pigmentary tissue proved, however, to be a matter of considerable difficulty. Tincture of cantharides and croton oil, which happened to be among the first substances which I employed with reference to this subject, resembled mustard in causing diffusion of the pigment. Taking, in the first instance, the same view of this change as the German authorities, I attributed it to the relaxation of contractile cells, and regarded its occurrence, in consequence of irritation, as an indication of loss of power in the tissues, a view which was in harmony with the nature of the derangement of the blood in a congested part. Croton oil, curiously enough, acted very slowly on the web, not producing any change on either pigment or blood

for an hour or more: also its effects appeared inconsistent with my theory; for while it ultimately gave rise to diffusion of the pigment to even a greater extent than I had seen occur with mustard, yet it induced only comparatively slight appearances of congestion. Chloroform also seemed at first still more anomalous in its operation, though in the opposite way; for though it was pre-eminently potent in inducing congestion, it caused no alteration whatever in the appearance of the pigment, whether mildly or strongly applied.

Afterwards, as the true nature of the pigmentary functions became unveiled, and further facts were developed, these difficulties were completely cleared away. The first step towards their solution was made in an experiment with ammonia. A frog being placed under chloroform, I covered the whole of the foot with sweet oil, except a small area in one of the webs, the pigment being in the stellate condition, *i. e.* about midway between perfect concentration and full diffusion. An assistant then held at a short distance above it a piece of lint soaked in the strongest liquor ammoniæ, so that its pungent alkaline vapour might play upon the exposed area, while the rest of the foot was protected by the oil. This having been continued for a few seconds, accumulation of corpuscles and stagnation occurred in the vessels of the area, without any change in the appearance of the pigment. After a while, however, the creature happened to grow pale, and, in the web generally, the pigment became completely concentrated so as to assume the dotted aspect, but in the part which was the seat of congestion it remained stellate as before. Hence it appeared that though the ammonia did not cause any change in the distribution of the pigment, it had in reality produced a great effect upon the chromatophorous cells, which, in the area exposed to its influence, had been deprived of the power of concentration by the mildest degree of action of the alkali that sufficed to induce stagnation of the blood. On examination of the web about four hours later, resolution of the stagnation was found to have taken place, though there was still some excess of corpuscles, with marked adhesiveness of the colourless ones in the vessels of the ammonia area. The creature was now released for the night. Next morning the integument was in the opposite extreme of colour, being almost black, and the pigment had the reticular appearance, being fully diffused throughout the whole web, except the central part of the ammonia area, where it retained the same stellate condition as the day before. Hence it appeared probable that the diffusive power, as well as the concentrating, had been paralysed by the ammonia, but had been recovered in all the area except the part that was likely to be the last to regain its functions. To ascertain whether the concentrating power had also been regained, I killed the frog and amputated the leg; soon after which the usual *post mortem* concentration took place completely in the web generally, while in the central part of the area the medium state was still retained, and in the rest of its extent concentration considerably beyond the medium state, but short of the full degree, supervened, showing that recovery of function had taken place to a considerable extent, but was not yet quite complete.

I now felt little doubt that chloroform also possessed the power of arresting the pigmentary functions; but in order to prove the fact I killed a dark frog, and placed one

of its legs in that fluid for half a minute, and then wrapped both it and the other leg in damp lint. After some hours the limb which had not been treated with chloroform was quite pale, while the other, having lost the faculty of *post mortem* concentration, remained as dark as before. The appearance presented by the pigment in the two feet is shown in Plate XLVII. figs. 1 and 2.

Mechanical violence proved similar in its effects on the pigment, which, in the area pinched, retained the same appearance as before, except that in parts where the pressure operated most severely the cells seemed sometimes to have suffered rupture. Fig. 2, Plate XLVIII. is a camera lucida sketch of part of a spot which had been compressed by means of padded forceps, with an adjoining uninjured portion of the web. The pigment was fully diffused before the experiment was performed, and remained so afterwards in the area squeezed, while it became concentrated elsewhere, and this was the condition of things when the drawing was made. The concomitant differences in tint between the blood in the affected and the sound parts in consequence of the accumulation of closely packed red discs in the former, are also strikingly shown in the sketch*.

The galvanic shock, too, produced no effect apparent to the eye upon the pigment of the parts in which it caused stagnation of the blood, but experiments afterwards made showed me that, like ammonia, it exerted a paralysing agency both upon the concentrating and the diffusive powers; and the same results ensued on the application of dry heat in the cases mentioned in the last section.

From these and other similar facts it appeared that mustard, croton oil, and cantharides are exceptional as regards the diffusion to which they give rise, the usual course being that irritants, when applied so as to produce stagnation of the blood, suspend at the same time both the functions of the pigment-cells.

It afterwards turned out that mustard was, in reality, no exception to this general rule. Subsequent experiments showed that diffusion takes place to very different degrees in different instances under the action of this substance, but that in all cases, after reaching a certain point, it becomes incapable of advancing further in the irritated part, however much it may increase in the body generally, in case of the animal changing to a darker colour. These differences depend partly upon the strength of the mustard, the diffusion being least when the irritant is most potent. Thus, on one occasion, when a solution of the volatile oil in spirit of wine was applied to a web in which the pigment was fully concentrated, congestion was very rapidly developed, without any alteration in the appearance of the chromatophorous cells. That the diffusion is

* Much more gentle pressure, if long continued, may give rise to similar results, as I happened to notice in the following manner. Being desirous of watching the process of *post mortem* concentration of the pigment, I amputated a leg of a dark frog, and, having stretched out the foot over a glass plate, put a small piece of thin glass upon part of one of the webs, and applied a high power of the microscope to it. I was disappointed to find, however, that the change I wished to observe did not take place; but on looking at other parts of the web, found that immediately beyond the edge of the slip of thin glass, the pigment was on all sides considerably concentrated, although remaining fully diffused where the glass covered it; an effect which I could attribute only to the gentle squeezing to which the two plates subjected the part of the web that lay between them.

in inverse proportion to the energy with which the mustard acts, was well illustrated by the experiment which furnished the drawing given in Plate XLVIII. fig. 1*. In that case, a frog having been prepared in the manner mentioned in the note to page 611, a portion of very strong mustard was placed upon the middle of one of the webs, the pigment being in the stellate condition, such as is seen on the left-hand side of the sketch, which represents a part of the edge of the spot to which the irritant was applied, together with an adjoining portion of the web. Shortly after this had been done, I noticed that the pigment was in a state of full diffusion in a ring round about the opaque mass, producing the reticular appearance shown in the stripe down the middle of the sketch. I had in a previous case seen a similar ring become affected with congestion, when a portion of mustard had been applied for a long time, in consequence of the pungent vapour of the volatile oil playing upon the neighbouring parts of the web, and there could be no doubt that the effect on the pigment in the present instance was due to the same cause; but in the latter no material change was as yet visible in the blood except close to the edge of the mustard, where the corpuscles were seen to be abnormally adhesive. After the lapse of about an hour, the area on which the irritant had lain being examined, was found to be the seat of the most intense inflammatory congestion, indicated in the drawing by the crimson colour of the vessels, but the pigment there had experienced only an exceedingly slight degree of diffusion, being, in fact, almost exactly in the same state as at the commencement of the experiment. Thus the vapour of the volatile oil, though operating too mildly to cause inflammatory congestion, nevertheless induced the highest possible degree of pigmentary diffusion; but the mustard, where it lay actually in contact with the web, and acted energetically upon it, arrested that very process of diffusion to which its gentler operation gives rise.

In the progress of the case it happened that the animal changed from the medium tint which it had at first to a very pale colour, the pigment, in the web generally, assuming the dotted condition depicted on the right-hand side of the drawing. Yet many hours after the mustard had been removed, the pigment on which it had acted retained its stellate disposition, and the reticular appearance in the surrounding ring also remained unchanged, showing that the power of concentration had been permanently lost in those parts, and affording a favourable opportunity for obtaining by means of the camera lucida a delineation of the medium, and both extreme conditions of the pigment in the same web. Next day the experiment was rendered still more instructive by the skin becoming excessively dark, the pigment undergoing full diffusion in the healthy parts of the web, so that the contrast between the ring about the congested area and the surrounding regions no longer existed: yet the stellate condition was still maintained where the mustard had lain, showing that it had suspended the faculty of diffusion no less than that of concentration.

Croton oil now no longer seemed anomalous in its operation. Its curiously slow action upon the frog is comparable to the mild influence of the vapour of mustard, and the slight amount of inflammatory appearance which I had sometimes observed in a

* This experiment was performed subsequently to the reading of the paper.

part where it had caused a great degree of pigmentary diffusion, is strictly analogous to the healthy state of the circulation in the reticular ring round the congested area in the last experiment.

Cantharides also presents a parallel case. Its action is even more slow than that of croton oil; and on referring to notes taken at an early period in this investigation, I find that in one instance, when two hours and a half had elapsed after the application of a small drop of the tincture to the web, though diffusion of the pigment had become apparent in the area on which it had acted, no change of the blood had yet been observed; and an hour and a half later, the red corpuscles, though abnormally adhesive as compared with those in surrounding parts of the web, were still moving slowly through the vessels.

Hence it appears that diffusion of the pigment may be produced by either of these three substances without the blood undergoing any material derangement, and therefore that its occurrence under their influence is to a great extent, if not entirely, independent of the inflammatory process. On the other hand, it has been demonstrated, as regards mustard, that when stagnation of the blood has been developed through its action, the state of the pigment-cells is the same as is induced by irritants generally, viz. a complete suspension of functional activity; and, from analogy, we may be pretty sure that this is also true of croton oil and cantharides, although their slow operation renders it difficult to obtain absolute proof upon the point.

In a physiological point of view, it is an interesting question, what is the cause of the diffusion of the pigment induced by these three irritants. I have shown elsewhere* that concentration is the invariable result of the action of the nerves upon the chromatophorous cells, and that diffusion takes place whenever they are liberated from nervous influence. Also in the tree-frog of the Continent, which is much more liable to changes in the colour of the integument, in consequence of direct irritation, than our own species, the invariable experience of the German observers was, that concentration followed the application of a local stimulus, while secondary diffusion sometimes occurred in the irritated spot, depending apparently upon exhaustion†. From these facts, diffusion ensuing on irritation cannot well be regarded as an increased action excited by the stimulus, but rather as an evidence of diminished vigour. With croton oil and cantharides, which have not an irritating vapour, the diffusion is exactly limited to the extent of the irritant, showing that it is due to a direct action on the tissues; and the most probable explanation of its occurrence appears to be that mustard, croton oil, and cantharides have the peculiarity among irritants of affecting the nerves of the pigment-cells in the part they act on, somewhat more rapidly than the cells themselves, and, paralysing the former while the latter still retain their powers more or less intact, permit diffusion to go on unrestrained by nervous influence, till the further operation of the irritant completely suspends the pigmentary functions. It may be objected to this view, that diffusion occurs on the application of these substances to an amputated limb, but, from evidence given elsewhere‡, it is probable that the pigment-

* See the paper "On the Pigmentary System," page 641. † See page 627. ‡ See page 640.

cells possess a local nervous apparatus, on which the occurrence and maintenance of *post mortem* concentration depend, and the paralysis of which, while the pigment-cells retain their powers, would give rise to diffusion in an amputated limb. Be this as it may, the fact that the state of full diffusion continued in the ring around the congested area in the last mustard experiment for hours after the irritant had been removed, although, during that time, complete concentration occurred in the web generally, is pretty clear evidence that the pigment-cells in that part had not merely been stimulated to increased action (for in that case they would have returned to their former condition soon after the stimulus had ceased to operate), but had suffered a loss of the faculty of concentration. Whether the loss of power resided in the nerves of the pigment-cells, or in those cells themselves, is a matter of indifference as regards the objects of the present inquiry; the important fact being that an action of the mustard so mild as to give rise to little or no derangement of the blood, nevertheless produced a certain degree of loss of power in the part on which it operated. There can be no doubt that the same principles apply to the cases of croton oil and cantharides; and thus the diffusion caused by these three irritants assumes a high interest, as visible evidence of diminished functional activity accompanying, if not preceding, the earliest approaches to inflammatory congestion in parts which have been subjected to their influence.

With the view of ascertaining the nature of the effect produced on the pigment-cells by the mildest action of chloroform which is capable of causing inflammatory disorder, I ascertained, by repeated experiments, the shortest time in which the vapour of that liquid gave rise to unequivocal signs of a congestive tendency in the web of the living frog; and having found this to be about half a minute, suspended one of the legs of a recently killed dark frog in a vessel, the bottom of which was covered with chloroform, having previously examined the webs microscopically, and found that full diffusion of pigment existed throughout them. The result was that the limb exposed to the chloroform vapour remained dark, while the other became gradually pale. On re-examination of the former after some hours, each web presented stripes of full diffusion of pigment alternating with others in a medium condition; their direction being at right angles to the margin of the web. The longitudinal folds in which the webs had happened to be, had prevented the chloroform vapour from gaining equally free access to all parts; yet the chromatophorous cells in the stripes that had been thus partially protected from its influence had been incapable of complete concentration, showing that even the exceedingly slight degree of action which the chloroform could have exerted upon these places sufficed to diminish, though not to destroy, the functional activity of the pigmentary tissue.

In one of the experiments performed in order to determine the effect of mechanical violence, as before alluded to, the pigment remained unchanged for days in the area which had been pinched, while varying in other parts of the web; yet, though great excess of red corpuscles existed in the vessels of the affected spot, they never ceased to move; showing that the functions of the pigment-cells might be completely suspended by a degree of irritation short of that which occasions actual stagnation of the blood.

The same thing was afterwards* seen in a case in which a small drop of wood-vinegar was placed upon one of the webs of a frog which had been deprived of the power of voluntarily moving the limbs by passing a knife between the occiput and the atlas, so as to sever the brain from the cord. The fluid being thus allowed to lie quite undisturbed, did not spread at all upon the web, which was dry before it was applied. It produced its effects very slowly, so that, after the lapse of three and a half hours, the blood in the area covered by it, while everywhere presenting inflammatory appearances, was still only partially stagnant. Yet throughout this space the pigment retained exactly the same moderate degree of diffusion as it had at the beginning of the experiment, although in the interval complete concentration had taken place elsewhere; and a very striking contrast was presented between the stellate pigment with the adhesive though still moving blood-corpuscles where the web was wet with the vinegar, and the dotted pigment and perfectly healthy circulation in the dry parts immediately adjacent.

Seeing, then, that complete suspension of the pigmentary functions may be caused by an amount of irritation which induces only a minor degree of congestion, and further, that (as we learn from the experiment with chloroform vapour) a still milder operation of an irritant renders these functions sluggish though not completely arresting them, we seem to have sufficient evidence that impairment of the functional activity of the chromatophorous cells occurs in the very earliest stages of that primary change in the tissues which leads to inflammatory derangement of the blood.

It was seen in the ammonia experiment related above, that resolution having taken place in the congested area, the pigment-cells of the part recovered the faculty both of diffusion and concentration. This might have been pretty confidently predicted; for as congestion is a necessary consequence of the disorder produced in the tissues by irritants, we might have been almost sure that the return of the vital fluid to that healthy condition in which it is fit for free transmission through the vessels, must be preceded by a restoration of the living solids to their normal state. In the case alluded to, however, no sign of recovery of the pigment-cells appeared till after the circulation had become re-established; and even when several hours had elapsed, they still remained paralysed in the central part of the area on which the ammonia had acted. This is in harmony with the fact lately pointed out, that complete suspension of the pigmentary functions may accompany a state of the blood short of actual stagnation; and both appear to depend upon the circumstance that the chromatophorous cells are an extremely delicate form of tissue.

The rate of recovery of the pigment-cells varies greatly, however, in different cases, and in this respect much depends upon the nature of the irritant. An example of an agent of this class producing only very transient effects on the pigmentary functions is presented by carbonic acid. It has been before mentioned that the immersion of a living frog for about a quarter of an hour in water highly charged with that gas, gives rise to complete stagnation of the blood in the webs, although the heart still continues beating, but that resolution occurs after the animal has been exposed for awhile to the

* This experiment was performed subsequently to the reading of the paper.

atmosphere. With a view to ascertaining whether the congestion was due to the direct action of the acid upon the tissues, I made the following experiment. Having killed a dark frog and amputated both legs, and ascertained by microscopic examination that the pigment was fully diffused in the webs, I put one limb into a bottle of "aërated water" and the other into ordinary water: the latter soon became pale through *post mortem* concentration, but the former remained as dark as ever during the two hours for which it was retained in the solution of carbonic acid, the direct action of which upon the bloodless tissues was thus demonstrated. An hour after the limb had been taken out, however, it was evidently recovering, being distinctly lighter in colour than it had been, and two hours later it was quite pale, and the pigment in the webs was found to be in almost the extreme degree of concentration. In subsequent similar experiments I left the leg in the aërated water for a longer time, during which it always retained precisely the same tint that it had when first introduced; and, if left for many hours, showed signs of loss of vitality, by the early supervention of cadaveric rigidity and exfoliation of the epidermis; but if it was taken out within about four hours, the pigment-cells recovered completely; and in one case a leg not removed for nine hours regained, nevertheless, to a considerable extent, the faculty of concentration*. Thus it appears that carbonic acid, though exercising a powerful sedative influence upon the tissues, and paralysing for the time their vital energies, so as to give rise to intense inflammatory congestion, yet, even after a very protracted action, leaves them in a state susceptible of speedy recovery.

Here we see for the first time a satisfactory solution of the much-debated problem of the cause of congestion of the lungs in Asphyxia; for there can, I conceive, be no doubt that the pulmonary tissues, exposed under ordinary circumstances to the influence of a free supply of oxygen, suffer, like those of the frog's web, from the vicinity of an abnormal proportion of carbonic acid, and inflammatory congestion is the necessary consequence. At the same time, the rapid recovery of the lungs from asphyxial congestion of considerable duration, when the normal atmosphere is readmitted, finds an equally close parallel in the speedy return both of the pigment-cells and the blood to the healthy condition when the foot of the frog is removed from the aërated water.

But the most important lesson to be learnt from these simple experiments with carbonic acid upon amputated limbs, is that the tissues possess, independently of the central organs of the nervous system, or of the circulation, or even of the presence of blood within the vessels, an intrinsic power of recovery from irritation, when it has not been carried beyond a certain point; a principle of fundamental importance, which has never before, so far as I am aware, been established or conjectured. It applies equally in the case of other irritants. Thus having transmitted for about a quarter of a minute, through one of the webs of a dark amputated limb, powerful galvanic currents, such as I had before ascertained to cause stagnation of the blood when operating for an instant upon the living animal, I found, after the lapse of an hour and a quarter, that the pro-

* This observation was made subsequently to the reading of the paper.

cess of concentration had advanced considerably in the next web, but in that on which the galvanism had acted had only just commenced, even in the parts most remote from the point to which the poles of the battery were applied; while in the vicinity of that spot the state of full diffusion still continued. After the lapse of three more hours, however, the pigment was almost fully concentrated in the part of the web where it was before only slightly so; and even where it had been most directly subjected to the galvanic influence, it had undergone a certain, though very slight degree of the same change, the chromatophorous cells having even there partially recovered their functions.

This inherent power in the tissues of recovering from the effects of irritation, explains the occurrence of resolution in an amputated limb, such as I once observed in a case where a moderate amount of congestion had been induced under the action of oil of turpentine before the animal was killed, and the blood resumed to a great extent its normal characters in the vessels several hours after the limb had been severed from the body.

The return of the blood along with the tissues to the state of health is a very interesting circumstance. Whether it depends upon an intrinsic power of recovery on the part of the vital fluid, or on the living solids resuming an active operation upon it, is at present uncertain; but in the mean time, the phenomena of resolution already assume a far more intelligible aspect than heretofore, on the hypothesis that the tissues generally are endowed with the same faculty of self-restoration as the pigment-cells.

It may be well to give here a list of all the agents whose effects upon the pigmentary functions I have investigated. They are as follow:—Mechanical violence, the galvanic shock, desiccation of the tissues*, dry heat, warm water at 100° Fahr., intense cold, caustic ammonia, a strong solution of common salt, carbonic acid, acetic acid, tincture of iodine, chloroform, oil of turpentine, mustard, tincture of cantharides, and croton oil.

These are all of them irritants, *i. e.* give rise to inflammatory congestion through their direct action upon a vascular part, as I have witnessed in the frog's web in every case except that of cold, the influence of which in causing intense inflammation in the human subject is, however, familiar to all †. All of them also afforded, in their effects upon the pigment-cells, ocular evidence of impairment of the functional activity of the tissues on which they act; and considering the number included in the list, and their great variety in essential nature, we need not hesitate to admit that similar effects are produced by the entire class of irritants.

There is another tissue in the frog's web which discharges functions apparent to the eye, viz. the arterial muscular fibre-cells, the contractions of which are readily recog-

* The effects of deficiency of moisture in the web were observed in amputated limbs, in which I have seen both suspension of pigmentary functions from this cause and recovery from that state after the application of water. While the circulation is going on in the living animal I have not found desiccation of the web to occur, unless the tissues had been weakened more or less by irritation.

† The only experiment which I made with cold was performed by introducing a test-tube, containing a dark amputated limb, into a freezing mixture of ice and salt at about 20° Fahr. for ten minutes. When the frozen limb had thawed, I ascertained, on microscopic examination, that the pigment had undergone a slight degree of *post mortem* concentration, but five hours later it was still in much the same condition.

nized in consequence of the changes of calibre which they produce in the vessels; and the manner in which the arteries are affected in a congested part of the web indicates that the muscular, like the pigmentary tissue, has its functional activity impaired by a certain amount of irritation. Thus I have repeatedly been struck with the fact, and noted it before I knew its significance, that an artery running through a limited area on which an irritant has acted, remains dilated in the spot, although it may vary in other parts of its course. This I have observed in one experiment with mustard, in one with acetic acid, in two with ammonia, and in one with heat. In the last-mentioned case the appearance was particularly striking, from the circumstance that two arteries happened to pass through the burnt part, and were constricted to absolute closure in the rest of their course, contrasting strongly with their fully dilated state within the area.

In the ammonia experiments also the artery concerned was, in the progress of each case, seen to be completely constricted beyond the congested area, though still dilated within it. The limitation of this effect on the arteries, to the extent of the part acted on by the irritant, proves that it is the result of its direct action on the tissues; differing remarkably in this respect from the dilatation of the vessels, which is produced indirectly through the medium of the nervous system, and affects a wide space round about the spot irritated.

But with regard to both the muscular fibre-cells of the arteries and the pigment-cells, it may fairly be questioned whether the diminution of power to act resides in them or in those portions of their nerves which are situated in the irritated region. The view that the nerves are paralysed by irritants is consistent with the benumbing influence well known to be exerted upon the human skin or mucous membranes by some of those agents, *e. g.* mechanical violence, the galvanic shock, cold, and chloroform. I have also observed, as before alluded to*, that mustard produces a similar result on the cutaneous sensory nerves, and hence it seems probable that the same is true of the whole class of irritants. Again, the diffusion induced by mustard, croton oil, and cantharides indicates, according to what we have seen to be its most probable explanation, that the nerves of the pigment-cells suffer impairment of functional activity under the action of these three substances. On the other hand, the fact that diffusion is arrested equally with concentration by most irritants, appears to prove that the chromatophorous cells are themselves also affected with loss of power; for, as has been before alluded to, the withdrawal of nervous influence from them in a healthy state of the tissues invariably gives rise to diffusion, and the same result would necessarily follow the action of an irritant which merely paralysed the nerves. I have also observed, on two occasions, after the energetic operation of an irritant upon a part of a web containing a large artery†, that drawing

* See page 677.

† The main arteries lying between the layers of skin of which the web consists, are not so speedily acted upon by irritants as the capillaries of the dermis. This is most marked in large frogs with thick webs. In one such specimen, a drop of chloroform caused first stagnation and then discoloration from chemical action on the blood in the capillaries of the dorsal layer of the web to which it was applied, while a main artery

the point of a needle firmly across the vessel failed to induce the slightest contraction in it, even at the very point crossed by the needle; proving that the muscular fibre-cells had lost their irritability. At the same time it is by no means improbable that the nerves of the arteries may suffer before their muscular constituents, just as in the intestines, after death, the functions of the intrinsic nervous apparatus are lost some time before muscular contractility ceases*.

The question whether the suspension of function induced by irritants is confined to the nerves or affects the tissues generally, being one of great interest, I was anxious to obtain clear evidence regarding it; and it occurred to me that valuable information would probably be derived from observing the effects of such agents upon the action of the cilia, which, though not present in the web of the frog, exist in abundance upon the mucous surfaces of the mouth and œsophagus of that animal. Dr. SHARPEY, in his celebrated article "Cilia" in the 'Cyclopædia of Anatomy and Physiology,' mentions experiments made by PURKINJE and VALENTIN, and also by himself, with a great variety of substances, including among the rest some irritants, which, when applied with sufficient energy, arrested completely, by their chemical action as it was supposed, the movements of the lashing filaments. It is evident, however, that in order to produce effects at all comparable to the state of the tissues of the frog's web in congestion, it would be necessary to adopt some more delicate method of experimenting, and the most eligible means for this purpose seemed to be to allow an irritating vapour to play upon a ciliated surface. Accordingly, on the 30th of November, 1857†, having cut off a small piece of the tongue of a frog killed about an hour before, and placed it upon a slip of glass under the microscope, with just enough water to permit the free play of the cilia, I held near to it a piece of lint soaked in chloroform, keeping my eye over the microscope. The effect was instantaneous cessation of the previously rapid action of the cilia, which now stood out straight and motionless, like the hairs of a brush. I now immediately withdrew the lint, after which the same state of complete inaction continued for about half a minute, when languid movements began to show themselves, and after the lapse of five minutes more the ciliary action was going on pretty briskly in some parts, and ten minutes later seemed to have almost completely recovered.

Thus chloroform vapour produced in the ciliated epithelium-cells a condition precisely similar to that brought about in the pigment-cells by irritants applied so as to cause inflammatory congestion of the web, viz. a state of suspension or temporary deprivation of functional activity. And as the removal of the epithelium-cells from the surface on which they grow does not arrest the movements of their cilia, no mere paralysis of nerves

lying beneath still contained blood of natural appearance, and showed evidence of languid contractility, while in the capillaries of the plantar layer of the web, the circulation was still going on in a pretty healthy state. This frog, however, seemed endowed with unusual powers of vitality in the tissues. This observation, as well as that in the text to which this note refers, was made subsequently to the reading of the paper.

* See the paper 'On the Functions of the Visceral Nerves,' before referred to.

† This date indicates that the experiments on the cilia have been performed since the paper was read.

could account for this result, which necessarily implied that the epithelial tissue itself was affected with loss of power to discharge its accustomed functions. In repetitions of this procedure upon the same and other portions of the tongue, I did not generally get complete cessation of movement of all the cilia, but usually some retained a languid action, which improved after the chloroform had been removed. In one instance, however, the same perfect stoppage took place as in the first case, and the recovery was also very general, though the returning action was languid. Under these circumstances, a piece of lint dipped in strongest liquor ammoniæ was brought within about 1½ inch of the object, and retained there for about fifty seconds, during which time the ciliary motion became progressively and greatly diminished, and within twenty-five seconds of the removal of the lint, had ceased altogether. Some water was then added, so as to get rid of the absorbed alkali, when the cilia soon began to move again, and within about three minutes their play was more vigorous and general than before the ammonia was used, and three minutes later it was universal, as it was prior to the application of the chloroform. On another occasion, in a different animal, the cilia having been ascertained to be in rapid motion on a fresh piece of tongue, lint containing liquor ammoniæ was held at a short distance from it for thirty-three seconds. The cilia very soon grew languid, and by the end of the time mentioned had quite ceased to act. The lint was at once withdrawn, but no recovery occurred; the operation of the irritant had been rather too energetic, and the vitality of the tissue had been destroyed. A languid state of the cilia was also produced by placing freshly prepared mustard near them, and improvement took place when it had been removed; but the essential oil itself, applied on lint like the chloroform and ammonia, though not acting so rapidly as might have been expected, permanently arrested the vibratile filaments. The vapour of strong acetic acid, if acting for four seconds, caused great diminution of the motion, and in another instance arrested it completely in five seconds. I did not, however, see any recovery from the effects of this agent, which produced obvious organic injury in the cells. The introduction of a portion of the mucous membrane of the mouth into a bottle of aërated water for about twenty minutes gave rise to permanent stoppage of the cilia, and similar treatment for three or four hours caused disorganization of the epithelium, whereas the same period of immersion in ordinary water did not arrest the cilia. Powerful interrupted galvanic currents, transmitted for a few seconds through a particular spot in a piece of tongue on which the cilia were in free movement, abraded a portion of the epithelium there, and arrested completely the cilia of adjacent cells still *in situ*, and rendered those of other parts of the specimen extremely languid in their action. But the most satisfactory results were obtained from experiments with heat, which has the great advantage over chemical irritants, that it leaves no material behind it to act upon the delicate tissue. On the 14th of December, 1857, having ascertained that steeping a piece of the tongue of a frog for five minutes in water of 110° Fahr. caused total and permanent cessation of ciliary action and desquamation of the epithelium, at $9^h\ 9^m$ P.M. I placed a portion of that organ, in which the vibratile movements were equable though rather languid, in water at 100° Fahr., and retained it there for a minute and a quarter, when it was trans

ferred to cold water. On examining it after the lapse of nearly two minutes, I found the cilia acting decidedly more briskly than at first, but in the course of the next quarter of an hour they flagged very much, and in many parts ceased to move altogether. By this time I had fixed the specimen securely at the bottom of a glass trough, which I now suddenly filled up with water at 102° FAHR., and on first catching sight of the object, within a quarter of a minute of this procedure, found all the cilia absolutely motionless. I then at once drew off the warm water with a siphon previously arranged; and no sooner had this been done, than movements already began to show themselves in the cilia, and their action increased rapidly on my filling up the trough with cold water, and in a short time was all but universal and brisk, far superior to what it was before the hot water was put in. After a few minutes more, however, it was again very languid, and ceased entirely in many parts. I now, at $9^h\ 38^m$, filled up the trough with water at 104° FAHR.: at $9^h\ 38^m\ 17^s$ the cilia were almost all motionless; by $9^h\ 38^m\ 55^s$ the trough had been again emptied, but at $9^h\ 39^m\ 5^s$ there was even less movement seen. Cold water was again poured in at $9^h\ 39^m\ 35^s$, and after eighteen seconds, action was reappearing in the cilia, and it continued to increase during the next seven minutes, at the end of which time it was again almost universal. At $9^h\ 52^m$ the cold water was drawn off, and the same condition of the cilia having been ascertained to exist, the trough was, at $9^h\ 52^m\ 27^s$, filled up again with water at 104° FAHR.; eighteen seconds after this had been done, the ciliary action was found much diminished, but had not fully ceased; and after nine seconds more, during which the warm water was drawn off, the cilia were still acting very slightly. Within twenty-three seconds of this time the trough was again filled with cold water: now, however, the epithelium was in many parts beginning to exfoliate, swelling up by endosmose in obedience to the ordinary laws of chemical affinity, and so indicating that it was losing its vitality. I also lost sight of the precise spot which I had been observing, but noticed that ciliary action was again going on pretty quickly in some places. There can be no doubt, although there was no opportunity for observing the fact, that the first immersion in hot water caused cessation of the ciliary action; and that being admitted, we have in this case suspension of function and recovery four times repeated in the same fragment of tissue in consequence of as many applications and withdrawals of the irritant. It is a curious circumstance that each recovery, except the final one, brought up the action of the cilia for a time to a better state than they had just before the last introduction of warm water. But the discussion of this and other circumstances in this case will be best reserved till after the mention of another set of experiments.

In order to eliminate the nerves completely from among the causes both of the suspension of function produced by irritants and the recovery from that state, it seemed desirable, if possible, to observe those occurrences in detached epithelium-cells, and on the 22nd of January 1859 I made the attempt to do so. At first, however, it proved more difficult than I had anticipated. It was of course easy to obtain the material to operate on, by gently scraping the surface of the palate of a recently killed frog with a knife, and placing the mucus-like product on a plate of glass with a drop of water. But the

tissue thus separated from its connexions was in an exceedingly delicate condition, and any agent used for arresting the action of the cilia was very apt to destroy at the same time the vitality of the cells. Thus when the object was warmed by placing the glass plate on a piece of iron at about 100° FAHR. for half a minute, the vibratory movements were arrested, but never recovered, and in a short time the cells swelled up by endosmose. It appeared probable that the tissue had suffered during the time required for the cooling of the glass; and in order to avoid this, and also prevent the object-glass becoming obscured by vapour from the warm water condensing upon it, the epithelium was placed between two slips of thin covering glass, kept from too close approximation by fragments of the same material interposed, the whole forming a layer so thin that it would be rapidly heated if any hot body were placed in its vicinity, and cool as quickly on its removal. A small cautery iron, with a bulbous extremity about as big as a hazelnut, just too hot to bear in contact with the finger, was now put behind the stage of the microscope, within about three-quarters of an inch of the object, the diaphragm plate having been removed to afford room for this being done without interfering with the light sent up by the reflector. The result, which I watched from the first, was the same that I had once before observed from the very gentle application of heat to a portion of a frog's tongue, viz. primary increase in the action of the cilia which had previously been languid*, but which, within ten seconds of the approximation of the cautery, were moving with great rapidity, and continued to do so for about twenty-five seconds, at the expiration of which their motion was seen to be diminishing, and after another minute and a half it was considerably more languid than at the beginning of the experiment. The cautery being now removed was found to be much cooled though still warm, and its withdrawal did not affect the cilia, which still remained much in the same state after the lapse of eight minutes. I now repeated the experiment upon a fresh portion of epithelium, but this time used the cautery red-hot, placing it about 2 inches behind the object: no sooner had this been done than the action of the cilia became excessively increased, but this did not continue for more than five seconds, when they became perfectly motionless. The hot iron was now at once withdrawn, but the cilia under special observation did not recover. In other situations in the same specimen, however, movements were observed in the course of the following minute, and it was still continuing seven minutes later, when a part having been brought into the field where there were two considerable groups of cells in moderate activity, the cautery was again applied at a distance of about 2½ inches. The motions of the cilia immediately became distinctly increased, but, as in the former case, this condition gave place in five seconds to universal quiescence. The iron was then removed, and on re-examination after three minutes, the cilia were again moving, though in a somewhat languid manner in both

* Professor WEBER of Leipsig observed several years ago that the action of cilia upon epithelium cells removed from the human nostril was increased by gentle warmth, but retarded by cold. In that case the elevated temperature was natural to the tissue, and might be supposed to operate by restoring it to its normal conditions. In the cold-blooded reptile, however, the accelerated movement under the influence of heat has, of course, a very different significance.

parts of the field. For the sake of confirmation I again operated in a similar manner upon another specimen, on which I performed no less than five successive experiments with similar results in all. In the first three of these trials I had the very same cilia under observation, and saw them time after time become first increased in action and then arrested under the influence of the cautery, and gradually recover after its removal. In some instances the times of cessation and of recovery were noted as follows:—In the first the cilia were arrested in two seconds after the application of the hot iron, but the exact time of recovery was not observed; in the second, cessation of movement was produced in two seconds, and return began in fifteen seconds; in the third, cessation was in fifteen seconds, and recovery also in fifteen seconds; in the fourth, the times were not noted; in the fifth, movement ceased in about two seconds and returned in twenty. The experiments were performed within about five minutes of each other, or sometimes less. It is also to be remarked, that there were some slight differences in the degree of heat of the cautery and its vicinity to the object.

These experiments are as instructive as they are simple and easy of performance. They show conclusively that a component tissue of the animal frame may, independently of the nervous system, have its actions either excited or paralysed by the direct operation of an irritant upon it, and that it may possess an equally independent power of recovery. Also in the accelerated movements of the cilia elicited by very gentle heat, as compared with the cessation of their vibrations under a higher temperature, we have a striking confirmation of the view which I had taken of the relaxation of the arteries and hollow viscera in consequence of nervous irritation*. For the law which we thus see regulating the effects of heat upon the epithelium-cells is precisely that which I had inferred must govern the action of afferent nerves upon nerve-cells; this law being, that an agency which, when operating mildly, stimulates a tissue to increased activity, may, when more energetic, temporarily arrest its functions. Whether or not the converse always holds, viz. that any agent which is capable of suspending the functional activity of a tissue may also excite it if applied with sufficient gentleness, or, in other words, whether irritants are in all cases also stimulants, seems very doubtful. As regards the nerves, such does appear to be the case; for while many, and probably all influences which induce inflammatory congestion cause temporary paralysis of sensation in parts on which they act severely enough, they all stimulate the afferent nerves in the first instance, as is shown by the reflex changes in the calibre of the arteries which occur round about any irritated spot. The nervous centres, too, present an illustration of the same principle, not only in the effects produced upon them by the nerves, as lately alluded to, but also in the excitement well known to be occasioned by small doses of many sedative narcotics, such as alcohol, opium, and chloroform, which may be regarded as special irritants of the nervous centres. In the case of the cilia, I have not observed primary increase of movement to be induced by any agent besides heat; but I am not prepared to say that it might not by careful management be made to occur with some other irritants.

* Vide *antea*, p. 666.

The pigment-cells in the common frog give very little indication of the stimulating properties of irritants, as is evident from several of the experiments which have been recorded in this section. In the tree frog, however, as we are informed by the German authorities, a part of the integument subjected to such influences rapidly assumes a pale tint, and that even in a portion of skin removed from the body. I have also several times noticed, after pinching the web of a common frog, that, although in the spot actually squeezed, the pigment-cells were deprived of their power of changing, a pale ring about one-sixteenth of an inch in breadth has gradually formed in its immediate vicinity in the course of the next hour; whence it seems probable that direct irritation tends to excite concentration in the English species as well as in the continental, but that in the former the effect is developed much more slowly, so that it is apt to pass unnoticed. I further, on one occasion, saw *post mortem* concentration greatly accelerated by heat*. It is doubtful, however, whether these results are due to direct action upon the pigment-cells; for in the tree frog, as well as in the English kind, the pale tint was not confined to the precise spot operated on, but affected a limited area of surrounding tissue; whence it seems likely that it is developed through the medium of a local nervous apparatus contained in the skin†. If this be true, we have no proof that the pigment-cells are capable of being stimulated except by nervous influence, although they are, as we have seen, peculiarly susceptible of suspension of function through the direct operation of irritants upon them.

With regard to the nature of the change experienced by the tissues when temporarily deprived of power by irritants, the primary increase of motion of the cilia, lapsing into quiescence, under the operation of heat, may suggest the idea of exertion followed by exhaustion. But that the state of incapacity is not dependent on previous action, seems clear from the fact that in the pigment-cells it is maintained and aggravated by an irritant continuing in operation after complete suspension of function has been induced, the same kind of effect being still produced upon the tissues which are unable to act as upon healthy parts. As an illustration of this, I may revert to the results of immersion of an amputated limb in aërated water. The carbonic acid, as we have seen, entirely pre-

* This observation was made as follows:—On the 2nd of December, 1857, having amputated the legs of a dark frog, I put them both into water of 100° Fahr., but removed the left limb within six minutes of its immersion and placed it in cold water, leaving the right for a quarter of an hour longer, at the end of which time it was considerably paler than the left, and the microscope showed that its pigment was more concentrated. But while the warm water had accelerated the process of concentration up to a certain point, it had ultimately paralysed the pigment-cells and rendered them incapable of further change; so that the right limb remained permanently of the same colour as when removed from it, whereas in the left, which had been subjected for a much shorter time to the noxious agency, concentration continued to advance, so that in twenty-five minutes that leg was as pale as the other, and after an hour more it was a good deal the lighter of the two. I may further mention that rigor mortis was already carried to the extreme degree in the muscles of the right limb when taken out of the water, but in the left this change did not commence till about twelve hours later. At this period the pigment in the left limb still showed signs of retaining its functions, while that in the right had a dirty, indistinct appearance, indicating that it had lost its vitality.

† See the paper 'On the Cutaneous Pigmentary System,' before referred to, p. 640.

vents the occurrence of *post mortem* concentration, implying that the powers of the chromatophorous cells are completely suspended by it within a few minutes at most of its first acting on the part; yet, however long the tissues thus paralysed are kept subjected to its influence, they remain without any sign of action. They will, however, recover speedily and completely if soon taken out and exposed to the air, so that the irritating gas may be dissipated; whereas if retained for several hours in the aërated water, they may, indeed, have their powers restored to a certain extent on removal from it, but exhibit only very feeble action. Such facts as these prove conclusively that the tissues may have their functional activity impaired without loss of vitality by the direct action of irritants, independently of any stimulating effects which may be at first produced by them; and also that the influence thus exerted is of an injurious tendency.

The imperceptible transition from suspension of function to loss of vitality displayed by the long-continued operation of carbonic acid upon the pigment-cells is also well illustrated by some of the experiments upon the cilia, especially those with heat and ammonia, which, unless employed with extreme caution, not only permanently arrested the vibratile filaments, but reduced the epithelium-cells to a condition in which they were amenable to the ordinary laws of chemical affinity. All irritants appear to be agents which, if operating with sufficient energy, completely destroy vitality, probably by inducing, through chemical or physical action, an irreparable derangement of the molecular constitution of the tissues. Their essential property, however, is that of causing, when applied somewhat more mildly, a minor degree of disturbance or disorder in the component textures of the body, which are rendered for the time being unfit for discharging their wonted functions*, though afterwards, by virtue of their innate powers, capable of spontaneous recovery, the rapidity and completeness of which bears an inverse ratio to the intensity and duration of the previous irritation. Lastly, these same noxious agents, if in a still more gentle form, operate, upon some of the tissues at least, as stimulants, rousing them to increased exertion of their vital functions. How this effect is brought about must, I believe, be only matter of uncertain speculation, so long as the real nature of life in the animal frame remains, as it probably ever will remain to our finite capacities, an impenetrable mystery.

It is an interesting circumstance that, in the experiments with warm water, the cilia, after recovering from the state of quiescence, moved for a while more briskly than they did immediately before the application was made. This increased action cannot be attributed, like the primary acceleration resulting from very gentle warmth, to a mild operation of the irritant; for the epithelium-cells must have been completely cooled down before it commenced. It must therefore be regarded as a true reaction on the part of the tissue, whether dependent on accumulation of vital energy during the period of suspended function, or excited, as by an irritant, by the state of disorder which the warm water had induced, seems uncertain.

* The word "irritant" is etymologically ill adapted to express the possession of this property; but as it is universally employed in professional nomenclature, it is perhaps best to continue to use it.

Considering the number and variety of the functions which direct observation has shown to be suspended by irritants, viz. pigmentary concentration and diffusion, ciliary motion and nervous action, it appears probable that all the vital processes are liable to similar temporary arrest.

Different tissues, however, seem to differ in the facility with which they are affected by irritants. The pigment-cells are very susceptible to their influence, as is indicated by the complete paralysis which we have seen to be produced in them by agencies that give rise to only a minor degree of inflammatory congestion; and also by the circumstance which I have often observed in the web of the frog, that, as in the choroid coat of the human eye, they become absorbed in parts which have been injured, having been deprived of vitality by causes which inflicted on other textures only a recoverable lesion. The epithelium-cells, too, are very sensitive to irritation, exhibiting its results more rapidly than can be accounted for merely by their exposed situation. In those which invest the mucous membrane of the mouth, the cilia with which they are provided furnish the opportunity of which we have availed ourselves, of observing the stage of suspension of function in consequence of very gentle treatment; and though the epidermis does not admit of this, it shows the further stage of loss of vitality by exfoliating after an amount of injury from which the immediately subjacent tissues readily recover. JOHN HUNTER was unquestionably correct in the opinion that the elevation of the cuticle in vesication depends not only on the effusion of serum beneath it, but on a primary separation arising "from a degree of weakness approaching to a kind of death in the connexion between the cuticle and cutis*." For I find that in an amputated limb free from blood, although no effusion of serum can occur, the epidermis becomes speedily loosened in a part to which an irritant is applied, as for example, in a web treated with oil of turpentine, whereas it remains elsewhere firmly attached for days if the weather be cool.

The temporary abolition of the normal relations between the blood and the tissues in inflammatory congestion†, must be added to the list of instances of suspension of vital properties by irritation. The tissues the healthy state of which seems most likely to be essential to that of the vital fluid, are those contiguous to it, viz. the walls of the blood-vessels; and that these are really deprived of their vital endowments during inflammation, seems implied by the character of the material which is transmitted through them in that condition. For we have seen that the vascular parietes differ, in the state of health, from all ordinary solids in being destitute of any attraction for the fibrine, if not positively repelling it‡, and that this is probably the cause of the merely serous character of the effusion which takes place in mechanical dropsy depending upon abnormal pressure of the blood within healthy vessels. On the other hand, the exudation of the liquor sanguinis in its integrity, such as occurs in severe inflammation, cannot, I think, be satisfactorily explained by the mere abnormal pressure of the blood pro-

* Works of JOHN HUNTER, PALMER's edition, vol. iii. p. 349.

† See close of last section. ‡ Vide *antea*, p. 674.

duced by dilatation of the arteries and concomitant obstruction in the capillaries; but seems naturally accounted for on the hypothesis that the walls of the vessels, like other tissues, lose, for the time, in inflammation, their vital properties, and, acquiring an attraction for the fibrine like that exercised by ordinary solids, permit it to pass without opposition through their porous parietes.

It may be well to present a brief summary of the principal results arrived at in the present section.

It appears that the various physical and chemical agents which, when operating powerfully, extinguish the life of the constituents of the animal body, produce by a somewhat gentler action a condition bordering upon loss of vitality, but quite distinct from it, in which the tissues are, for the time being, incapacitated for discharging their wonted offices, though retaining the faculty of returning afterwards, by virtue of their own inherent powers, to their former state of activity, provided the irritation have not been too severe or protracted. This suspension of function or temporary abolition of vital energy is the primary lesion in inflammatory congestion; the blood in the vicinity of the disabled tissues assuming the same characters as when in contact with ordinary solid matter, and thus becoming unfit for transmission through the vessels; while the return of the living solids to their usual active state is accompanied by a restoration of the vital fluid to the healthy characters which adapt it for circulation.

CONCLUSION.

It remains to glance at the application of the principles established in the preceding pages to human pathology.

The *post mortem* appearance which is universally admitted to indicate that the early stages of inflammation have occurred during life, is intense redness, depending essentially not upon peculiar distension of the vessels with blood, but upon abnormal accumulation of the red corpuscles in their minutest ramifications. A beautiful example of this condition, developed idiopathically, was presented by the case of incipient meningitis mentioned in the Introduction, in which the vessels of an affected spot of pia mater were filled with a crimson mass of confusedly compacted corpuscles, exactly as in an area of the frog's web to which mustard has been applied. The derangement of the vital fluid in the human subject being thus closely parallel to that which we have studied in the batrachian reptile, we can hardly doubt that in the former, as in the latter, the living solids are in a state of more or less complete suspension of functional activity during inflammatory congestion. This view is supported by the effusion of liquor sanguinis in its integrity in the more advanced stages of the disease in man, and by the speedy coagulation of fibrine upon inflamed serous surfaces, or in the interior of vessels affected with arteritis or phlebitis. For these circumstances, as has been before remarked, appear to indicate that the tissues are for the time being reduced still more towards the condition of ordinary solid matter. These arguments, derived from the appearances of the blood,

are further corroborated by the immediate transition which is apt to occur from intense human inflammation to gangrene*.

But a comprehensive and complete account of the inflammatory process must embrace not merely the state to which the tissues are brought when the disease is fairly established, but also the causes which lead to it.

Inflammation is sometimes brought about in man in a way strictly analogous to that in which we induce it in the web of the frog's foot, viz. by the immediate operation of some noxious agent from without, as when boiling water is poured upon the skin. One peculiarity connected with such cases, as compared with those which are of idiopathic origin, is the great rapidity with which the various stages of the disorder are often developed. This, however, is the natural consequence of the direct manner in which the prejudicial influence is exerted upon the tissues; the inflammatory phenomena supervening more speedily in proportion to the energy of the irritant. This principle is well illustrated by the effects of mechanical violence upon the human integument. A moderate degree of pressure applied continuously gives rise, during the first few hours, to nothing more than inflammatory congestion, which disappears soon after the pressure has been removed, as seen in the red mark produced upon the forehead by a tightly-fitting hat. But if such treatment be continued for a considerably longer period, vesication will result, as when apparatus employed for the treatment of fractures is applied too firmly for many hours together over a bony prominence. The same effect which is thus slowly developed under a moderate degree of mechanical irritation, may, however, be induced very rapidly through the same agency in a more intense form, as is shown by the bullæ which are often observed in surgical practice very soon after the infliction of a severe contusion. Here the source of irritation being no longer in operation, there is no blush of redness in the vicinity dependent upon arterial dilatation, and hence such cases are often supposed to have nothing in common with inflammation; and I have known these vesicles mistaken for evidence of gangrene, so as to lead to unnecessary amputation. The suddenness with which inflammatory œdema arises in consequence of the bites or stings of venomous reptiles is explicable on the same principle. The poison appears to diffuse itself among the tissues so as to operate directly upon them, and when extremely virulent, kills them outright; but when less potent, produces merely a temporary though rapid prostration of their vital energies with consequent inflammatory effusion. Again, the congestion of the lungs, which comes on so quickly in asphyxia, has been before alluded to†, as probably the result of the sedative influence which, from experiments upon the frog, we are led to believe must be produced upon the pulmonary tissue by the abnormal amount of carbonic acid in the air-cells.

In the class of cases hitherto considered, the derangement of the part, and the causes which lead to it, being both, to a considerable extent, understood, the disease may, I think, be regarded as in so far satisfactorily explained. But one important lesson taught

* The degenerations of tissue which result from inflammation, ably delineated by Mr. PAGET in his 'Lectures on Surgical Pathology,' are additional evidence in the same direction.

† See page 687.

FRANK INSTITUT LIBRARY

by the results of this investigation is, that it is necessary to draw a broad line of demarcation between inflammation produced by direct irritation, and that which is developed indirectly through the medium of the nervous system, whether in the immediate vicinity of a source of irritation, as around a tight stitch in the skin, or a thorn in the finger, or at a distance from the disturbing cause, as when the kidneys are affected in consequence of the passing of a bougie, or the lungs through exposure of the feet to cold. Nothing can better illustrate the importance of this distinction, than what takes place in a recent wound. In consequence of the injury inflicted by the knife, together with the subsequent manipulation and exposure, the tissues, in a thin layer at the cut surface, are thrown into that condition which leads to effusion of liquor sanguinis, the fibrine of which, speedily coagulating, remains to constitute the bond of primary union, while the serum trickling away between the lips of the wound produces the discharge which soaks the dressing during the first twenty-four hours. But neither during the exudation of the lymph in such a case, nor during its subsequent organization, is there necessarily any inflammation induced in the lips of the wound through the nervous system; and if this complication does occur, it interferes with the healing process in a degree proportioned to its intensity. In other words, while a certain amount of inflammation as caused by direct irritation is essential to primary union, any degree of it as induced indirectly is both unnecessary and injurious.

The question how inflammation is developed through the medium of the nervous system, possesses a high degree of interest, in consequence of its bearing upon the manner in which counter-irritation operates therapeutically. In the integument, where we have the opportunity of seeing the affected part, the first indication of the supervention of inflammatory disorder around a centre of irritation is a blush of redness, which, as before shown *, consists, in the first instance, of mere dilatation of the arteries with rapid flow of blood through the capillaries. It is quite conceivable that arterial dilatation, carried to an extreme degree along with powerful action of the heart †, may so increase the tension upon the tissues as to impair their powers gradually by mechanical irritation, just as the frontal integument is affected by long-continued gentle pressure from without, as above alluded to; for we know that when inflammation does exist, mere increase of tension upon the blood in the vessels will greatly aggravate the disorder, as when an inflamed foot is kept in a dependent posture. Supposing this to be the whole mechanism of the disease, its origin would be sufficiently intelligible; for we have seen that vascular dilatation caused by irritation operating through the medium of the nervous system appears to depend on a depressing influence produced by excessive action of the afferent nerves upon the ganglia which preside over the arterial contractions. There are, however, some circumstances, such as the dryness of the nostril which may exist in the early stages of coryza, and sudden suppression of urine in consequence of

* See page 665.

† It is to be observed, that in the frog, when full dilatation of the arteries lasts for days together without the production of inflammatory congestion, the state of the vessels has been brought about by a very serious operation which greatly weakens the action of the heart.

urethral irritation in cases where renal congestion becomes ultimately established, which seem to indicate that other functions as well as arterial contraction may be primarily arrested by nervous agency in the early stages of inflammation. The study of the pigmentary system of the frog has afforded proof that other tissues besides muscular fibre are under the control of the nerves, and it seems not unlikely that gland-cells or other forms of tissue may, like nerve-cells, be reduced to a state of inactivity by excessive nervous action; and thus we seem to have a clue to comprehending what at first appears anomalous, that prostration of the vital energies of the part actually inflamed may be brought about by unusually great activity in the parts of the nervous system specially concerned with it. This, however, is a wide subject, which requires further investigation. But in the mean time we may, I think, consider as satisfactorily established the fundamental principle, that whenever inflammatory congestion, or, in other words, that disturbance of the circulation which is truly characteristic of inflammation, exists in any degree, the tissues of the affected part have experienced to a proportionate extent a temporary impairment of functional activity or vital energy.

Explanation of the Plates.

PLATE XLVII.

illustrates the anatomy and physiology of the cutaneous pigmentary system of the frog.

Figs. 1 and 2 are sketched from webs of different feet of the same animal. The creature was dark when it was killed, but one of the legs afterwards underwent the usual *post mortem* change to a pale colour, and such was its state when fig. 2 was drawn. The other limb was deprived of the power of thus altering by immersion for half a minute in chloroform; and fig. 1 shows the appearance of the colouring matter in the permanently dark condition of the integument.

Fig. 3 represents two chromatophorous cells with the pigment-granules fully diffused, the animal having been at the time coal-black. The bodies of the cells are seen to be pale, containing chiefly colourless fluid, while some of the finest branches of the offsets are quite black, in consequence of the dark molecules being closely packed together in them. In the same figure a capillary fully distended with blood-corpuscles is also given.

Fig. 4 represents the colouring matter in the same two cells during the progress of the process of concentration. The dark molecules are already for the most part collected about the middle of the body of each cell; but in the very centre of each cell is a pale point, where the granules seem not yet to have insinuated themselves between the cell-wall and the nucleus. The same capillary is here seen much reduced in calibre.

Fig. 5 shows the pigment in the lower of the two cells, concentration being still further advanced.

In fig. 6 the process is seen to be almost absolutely completed, the molecules being almost all of them aggregated into a black circular mass, occupying the middle

of the body of the cell, the more circumferential parts of which contain only colourless fluid, and are therefore invisible.

Fig. 7 is an outline of the wall of a large blood-vessel, with chromatophorous cells in its external coat. The pigment is almost completely concentrated, but the form of the section of the black masses, where they are seen edgewise, shows that they are not spherical, but disc-shaped.

Figs. 8, 9, and 10 are drawn, with a much higher power, from young frogs, with small pigment-cells: they exhibit especially the form and relations of the nucleus.

In fig. 10 the pigment is shown in an unhealthy state, the molecules being irregularly aggregated.

PLATE XLVIII.

represents the effects produced by irritants upon the pigmentary tissue and the blood-vessels of the frog's foot.

Fig. 1 shows the results of the application of mustard to the web. The pigment was at first in the stellate condition as on the left-hand side of the sketch, and it remained permanently in that state in the part on which the mustard lay, while at the same time intense inflammatory congestion was produced there, indicated by the deep red colour of the vessels. Just beyond the edge of the mustard the irritating vapour of the volatile oil gave rise to full diffusion of the pigment (an effect peculiar to mustard and a few other irritants when acting mildly), but without material inflammatory disorder of the blood; as seen in the stripe down the middle of the drawing. During the progress of the case the animal changed to a pale colour in the body generally, assuming the dotted aspect depicted on the right-hand side of the sketch in all parts which had not been acted on by the mustard, and thus deprived for the time being of the power of concentration. It will be observed that the blood-vessels of the healthy part are not materially smaller than those of the congested region; the deep colour of the latter being due to their containing closely-packed red corpuscles, while the former are pale in consequence of the blood within them having the normal proportion of colourless liquor sanguinis.

Fig. 2 illustrates the effects of mechanical violence. The lower half of the sketch represents part of an area in one of the webs of a dark frog, which was pinched with a pair of padded forceps so as to give rise to inflammatory congestion. The animal afterwards grew much paler, so that in healthy parts the pigment assumed the angular or slightly stellate appearance shown in the upper part of the drawing. But in the particular spot on which the mechanical violence had operated, the chromatophorous cells being incapable of discharging their usual functions, the pigment remained in the fully-diffused state in which it was at the commencement of the experiment.

XXXII. *On the Structure of Lavas which have consolidated on steep slopes; with Remarks on the Mode of Origin of Mount Etna, and on the Theory of "Craters of Elevation."* By Sir Charles Lyell, *F.R.S., D.C.L.*

Received June 10,—Read June 10, 1858*.

CONTENTS.

Part I.

Page

ON THE STRUCTURE OF MODERN LAVAS WHICH HAVE CONGEALED ON STEEP SLOPES ON MOUNT ETNA 705

Preliminary remarks on the characters commonly attributed to lavas which have consolidated on steep slopes, and on the theory of "Craters of Elevation" ... 705

Recent shower of ashes, September 1857, from the summit of Etna 709

Alluvial deposits and external features of the coast along the eastern base of Etna 709

Highly inclined stony lava of Aci Reale 711

Section of lava of the year 1689, inclined at 35°, in the Cava Grande 716

Structure, aspect, and inclination of the lavas of the great eruption of 1852–53 ... 719

Narrative of the eruption 720

Burnt area 724

Gigantic parallel ridges near the Portella of Calanna 726

Steeply inclined branch of the lava of 1852 at the head of the valley of Calanna 730

Obliteration of the junction-lines of successive and overlying lava-streams 732

Steeply inclined modern lava in the Cava Secca near Zafarana 733

Compact Lava of modern date, inclined at 35°, below the Cisterna 734

* [This paper was read to the Royal Society on the 10th of June, 1858, and a full abstract of it was printed in the 'Proceedings' for that month. In September of the same year I revisited Naples and Sicily, for the sake of re-examining certain points in the geology of Vesuvius and Etna, devoting five weeks to the exploration of the latter mountain. The additional facts and inferences obtained at that time have, by leave of the Council, been embodied in the present memoir; all the newly-intercalated passages being marked by *brackets*, thus [ ], or such as are simply recasts of the original MS., thus ☙[ ]❧. By comparing the abstract published in June (Proceedings of the Royal Society, June 10th, 1858) last with the present memoir, it will be seen that they agree with each other in all essentials, whether of fact or theory.]

Page
Highly inclined modern Lava near the Montagnuola 736
Recapitulation of Part I. 737

Part II.

ON THE STRUCTURE AND POSITION OF THE OLDER VOLCANIC ROCKS OF MOUNT ETNA, AS SEEN IN THE VAL DEL BOVE, AND ON THE PROOFS OF A DOUBLE AXIS OF ERUPTION ... 738
Proofs of a double axis—cones of Trifoglietto and of Mongibello 738
Comparison of the twofold axis of Etna with that of Madeira 744
Want of continuity of the older and modern parts of Mount Etna, and truncation of the summit 745
Elliptical crater, and question as to three centres of eruption discussed..... 746
Hypothesis of upheaval by injection or the formation of dikes, and on the inclination of old lavas in the cliffs of the Val del Bove 748
Supposed frequent injection of lava in beds parallel to strata of tuff considered ... 751
Evidence of pseudo-parallelism and want of uniform thickness of the beds forming the escarpments of the Val del Bove 753
Analogous form and arrangement of ancient and modern lavas 756
Flexures and arches in ancient lavas 758
Dikes in the Val del Bove 759
Lateral cones of Etna 760
Recapitulation of Part II. 761

Part III.

ON THE RELATION OF THE VOLCANIC ROCKS OF MOUNT ETNA TO THE ASSOCIATED ALLUVIAL AND TERTIARY DEPOSITS, WITH REMARKS ON THE THEORY OF "CRATERS OF ELEVATION" 762
Origin of the Val del Bove, and how far due to aqueous erosion 762
Alluvium of Giarre 763
Val del Tripodo, and proofs of aqueous erosion anterior to the Val del Bove... 764
Section of alluvium and basaltic lava between Giarre and La Macchia 767
Hypothesis of a series of subsidences and lateral explosions in the Val del Bove 768
Flood of 1755 in the Val del Bove 770
Gradual rise of the sea-coast and inland sea-cliffs at the eastern base of Etna... 772
Alluvium of the northern, south-western, and southern base of Etna..... 773
Volcanic eruptions in the alluvial plain of the Simeto 774
Upraised fluviatile and marine deposits of the old estuary of the Simeto 775
Ancient tuffs of Fasano, near Catania, with leaves of terrestrial plants 776

Page

Age of the marine tertiary strata of Cefali, Nizzeti, and Catira 777

Modern date of the mass of Etna 780

Recapitulation of Part III., and concluding remarks on the theory of "Craters-of-elevation" 781

APPENDIX.

A. Description of fossil plants from the volcanic tuff of Fasano near Catania, by Professor OSWALD HEER 782

B. List of fossil shells from the Newer Pliocene of Nizzeti, by Professor ANDREA ARADAS, of Catania 783

C. List of fossil shells and Echinoderms from Catira, near Catania, by Signor GAETANO G. GEMMELLARO 786

PART I.

ON THE STRUCTURE OF MODERN LAVAS WHICH HAVE CONGEALED ON STEEP SLOPES.

Preliminary remarks on the characters commonly attributed to lavas which have consolidated on steep slopes, and on the theory of "Craters of Elevation."

THE question whether tabular masses of lava having a compact and stony texture, and a thickness of many feet, can be formed on slopes inclined at angles of from 10° to 40°, has of late years acquired considerable importance, since geologists of high authority have assumed that if the inclination exceed 5° or 6°, a lava-current will be scoriaceous in texture, fragmentary in structure, and insignificant in thickness. Such steeply-inclined currents, it is said, can never give rise to beds of compact rock, comparable to those solid layers which we see, alternating with scoriæ and tuff, in the older parts of volcanic mountains, such as the escarpments of Somma in the case of Vesuvius, or the cliffs surrounding the Val del Bove in the case of Etna.

It has even been laid down as a rule by one geologist of eminence, the late M. DUFRESNOY of Paris, that lavas, to be compact and crystalline, must have consolidated on a slope not exceeding 1° or 2°. He states, in his memoir on "Vesuvius and its Environs" (1834), "Les laves ne sont compactes et cristallines que lorsqu'elles se sont répandues sur un sol ayant 1 degré à 2 degrés au plus d'inclinaison. . . . . Lorsque la pente du terrain est supérieure à 2° la texture compacte commence à s'effacer, les laves deviennent bulleuses et même scoriacées. Les coulées, qui se présentent sous un angle de 4° ne sont plus que des agglomerations de fragments incohérents*." M. ELIE DE BEAUMONT, in his

* "Terrains volcaniques des environs de Naples," Mém. pour servir à une description géol. de France, tome iv. p. 342.

"Recherches sur le Mont Etna," says (in the same volume, p. 184) that the solid beds of ancient lava in the Val del Bove (which dip often at 28° and upwards) resemble those portions only of a modern current which have flowed over ground almost flat, or not sloping at an angle of more than 3°. And again, speaking of the Vesuvian lavas seen in the Fosso Grande, he observes, "they attain a thickness of 4 or 5 metres when horizontal, but are thin on slopes of 5° or 6°" (ib. p. 169).

From these premises it has been logically inferred that almost all volcanic mountains, whether active or extinct, have acquired their present conical form, not by eruption, or the reiterated outpouring of lava and outthrow of ashes from one or more central craters, but by upheaval, or the upward and outward pressure of gases and fluid matter rising from below and disturbing the position of lavas and tuffs previously horizontal. For wherever we obtain access to sections displaying the internal structure of large volcanic cones, we find a series of stony layers several feet or yards in thickness, inclined at angles of from 10° to 30°, and sometimes, though rarely, more than 35°; and if it be true that the law above laid down does really govern the congelation of melted matter, the whole excess of dip above 2°, or according to some authorities above 5° or 6°, must have been due to mechanical force, or to some cause capable of altering the original position of the beds. Accordingly the following hypothesis has been suggested:—A dense series of horizontal or nearly horizontal sheets of lava and scoriæ having been deposited, a force operating from below and exerting a pressure both upwards and outwards from a central axis towards all points of the compass, has uplifted suddenly the whole stratified mass and made it assume a conical form, giving rise at the same time, in many cases, to a wide and deep circular opening at the top of the cone, an opening called by the advocates of this hypothesis a "Crater of Elevation."

When I first visited Vesuvius and Etna in the autumn of 1828, I was so struck with the analogy of the ancient and modern portions of those volcanos, that it appeared to me in the highest degree unphilosophical to imagine that they could owe their form to operations differing in kind or degree from those witnessed during ordinary eruptions. Seeing that the injection of lava into fissures, and the consequent formation of dikes, had occurred in the most modern part of the cone of Vesuvius, I included dikes among the products of ordinary eruptions, and inferred that an adequate lapse of years alone was required to reproduce gradually such volcanic mountains as had been formed in the course of previous ages. My grounds for adopting such an opinion were stated fully in the first volume of my 'Principles of Geology,' published in 1830 (see pp. 345, 394, chaps. 20 and 22), in which, as well as in the third volume published in 1833 (p. 84), I objected to the theory of Elevation-craters, first propounded by the late Baron Leopold von Buch.

Mr. Scrope, in his 'Considerations on Volcanos' (1825, p. 156, § 4), had previously advocated the same views, and had dwelt emphatically on the increase both in solidity and bulk imparted to volcanic cones, by the injection of lava into fissures in the heart of the mountain. He had moreover admitted, in a paper read to the Geological Society

in 1827, in which he combated VON BUCH's theory of "Erhebungskratere," that the frequent earthquakes which accompany eruptions and are connected with the injection of lava from below, imply the expansion of the solid framework of the cone, but he still insisted on the doctrine that "the parallel and sloping beds which with a quâquâversal dip compose every volcanic cone, were not originally deposited horizontally, or otherwise than at a high angle of inclination, and the angular elevation they have since sustained is in general comparatively trifling*." Yet neither Mr. SCROPE nor I, when we ascribed a volcanic cone to the cumulative effect of reiterated eruptions, claimed any originality for so obvious an explanation of the phenomena. For true it is, as M. ELIE DE BEAUMONT had remarked, that "Philosophers and geologists, who from the time of the Greeks to our own days have seen Etna covering its flanks with new beds of ashes, scoriæ and lava, have admitted, almost without examination, and as a self-evident fact, that the entire mountain is simply the result of the gradual addition one over the other of elements mutually similar, and all resembling the products of the eruptions which they themselves have witnessed" (ib. p. 101).

After the publication of the memoirs above cited of MM. DUFRESNOY and E. DE BEAUMONT, all geologists who implicitly acquiesced in the doctrine laid down by them as to the law which governs the consolidation of lava, became, almost unavoidably, converts to VON BUCH's hypothesis; for it was not only necessary to admit a vast amount of upheaval, but to assume that the whole of it had in each volcano been posterior in date to the outpouring of all, even the latest of the highly-inclined lavas, found in each cone.

Without attempting in this place to sketch the progress of a long controversy to which this question gave rise, I may refer to M. D'ARCHIAC's able analysis of the memoirs relating to it, in the first volume of his 'Histoire des progrès de la Géologie,' published in 1847, in attestation of the deep impression which the "Elevation-crater" theory had then made on the minds of not a few of the most experienced geologists in Europe. At the same time, it will be seen in the same chapter that some strong protests were made against it; one in particular by my friend the late M. CONSTANT PRÉVOST, in his account of the new volcanic island which rose in the Mediterranean in 1831. Ascribing its origin to eruption and not to upheaval, he took an opportunity in that memoir of adducing arguments derived from the structure of Vesuvius, Etna and other mountains, against the theory of VON BUCH†.

After I had given in successive editions of my 'Principles of Geology,' from the first to the ninth, and in a paper on the structure of volcanos, published by the Geological Society in 1849‡, my reasons for rejecting the "Crater-of-elevation" theory, I visited Madeira in 1853–54, and examined its structure, in company with Mr. GEORGE HARTUNG of Königsberg. We went also together to the Canaries, where we studied the island of Palma, which had been expressly selected by VON BUCH as a type of what he styled a

* Trans. Geol. Soc. London, 2 Ser. vol. ii. p. 341, 1827.

† Mém. de la Société Géol de France, vol. ii.

‡ See 'Proceedings' for that year, p. 207.

"Crater of Elevation." These explorations convinced me more than ever of the untenable nature of the hypothesis which attributes so preponderating an influence in the formation of volcanic cones to movements from below, whether paroxysmal or gradual, whether concomitant with, or posterior to, the accumulation of the successive products of eruption*.

In the course of my examination of Madeira and Palma, I had seen modern lavas, inclined at high angles from 15° to 20°, which had evidently not changed their position from the time of their origin, and which nevertheless were in great part of stony structure. Mr. HARTUNG, during a visit to Lancerote, one of the Canaries, in 1855, observed a basaltic lava, compact and continuous, which had congealed on the side of a modern cone called the Corona, at an angle of 30°, and which he traced for a space of 20 feet down the steep slope, the thickness of the layer increasing from 2 to 4 feet, with a breadth of about 35 feet. This current was not more vesicular than some of the oldest lavas of Madeira or of Etna.

Mr. DANA also, in his 'Geology of the Exploring Expedition of the United States' (1849), had remarked that the lava of Mount Loa, one of the Sandwich Islands, cools so suddenly, as to be capable of consolidating on steep slopes, sometimes of 25°.

But no observation was so much in point, in reference to this question, as that made by Signor SCACCHI, who in 1850 saw a compact stony lava, which in that same year had flowed down the flanks of Vesuvius, from near the margin of the great crater to the base of the cone in the Atrio del Cavallo, having a thickness of from 1½ in the upper to 4½ feet in its lower part, and dipping at angles varying from 32° to 38°. The interior of this current was laid open to view by a rare accident, namely, the sinking down, in February 1850, of a certain portion of the north flank of the cone, whereby one side of the new lava-stream was engulfed, and a section of the interior of the remainder rendered visible. This lava produced scarcely any scoriæ, whether above or below it, and exhibited hardly any vesicles in its texture. Although it had cooled on an average declivity of 35°, there was no distinction, in regard to compactness of texture, between it and those lavas of known date at the foot of Vesuvius that have congealed on perfectly level ground †.

* For observations on the structure of Palma, made by Mr. HARTUNG and myself in 1853–54, and theoretical conclusions thereon, see p. 498 *et seq.*, of LYELL's 'Manual of Geology,' 5th edition, 1855.

† SCACCHI, Memoria sull' incendio Vesuviano del 1850 et 1855, pp. 44, 65, and 145.

[Professor PIAZZI SMYTH informs me that in 1856 he observed, within 1700 feet of the summit of the Peak of Teneriffe, at the Alta Vista, a point 10,500 feet above the level of the sea, a bed of dark green obsidian with crystals of glassy felspar, resting on an average slope of 28°. The thickness of the inclined lava (the interior of which has been laid open partly by aqueous action and partly by fractures assisted by gravity) is from 3 to 7 feet. The rock is dense and compact in its lower part, but vesicular towards the surface, from which a covering of pumiceous scoriæ appears to have been washed away. The width of the lava is 200 feet, and it was traced for about 250 feet down the slope of the cone. Dips of 15° and 25° were seen in the solid continuous layer, which is very modern with reference to the Peak and the uppermost of all the lavas on the ridge where it occurs; but powerful streams of still later date, having an aggregate depth

After reflecting on these and other analogous facts, I was desirous, before publishing in detail the observations which Mr. HARTUNG and I had made in Madeira and the Canaries, to revisit Vesuvius and Etna, which I accomplished in the autumn of 1857. In studying Mount Etna, my attention was principally directed—1st, to the lithological character of those modern lavas which have consolidated on steep slopes; and 2ndly, to the question whether any proofs can be found, in the position of the ancient lavas and tuffs of the great volcano, in favour of the doctrine that the upheaving rather than the eruptive force has exerted a dominant influence. I hope at no distant time to offer to the Society the results of my observations on Vesuvius and some of the cones and craters of the Phlegrean fields, considered in reference to the same questions.

Recent Shower of Ashes of Sept. 1857 *from Etna.*—On my way to Catania (October 1857), I was shown, when passing through Aci Reale, some of the pulverized scoriæ which had been showered down on that city a few weeks before, on the 6th of September, 1857, from the summit of Etna, no less than fourteen miles distant. I was informed, that while this dust was falling on the roofs of the houses and pavement of the streets, loud detonations were heard at Aci, and a whirling column of dense smoke was seen to rise from the crater. The shape of the cone at the same time underwent a marked change, in consequence of which it now deserves even more than formerly its ancient epithet of "bicornis." [When I ascended to the summit of Etna, October 1858, I found that this same fall of sand and lapilli, being a hundredfold more voluminous near the focus of eruption, had levelled up the superficial irregularities of the lava of 1838, lying at the eastern base of the cone to such an extent that I could cross it with my mule. I also saw large angular fragments of a dark dolerite, 3 or 4 feet in diameter, thrown out at the same period to great distances from the crater, and resting on the gently inclined slope S.E. of the base of the cone. My guides assured me that the highest part of the rim of the crater had lost much in height during these explosions.]

Alluvial deposits and external features of the coast along the eastern base of Etna.

[When travelling by the coast road along the eastern base of Etna, the geologist cannot fail to be struck with the extent and thickness of an alluvial deposit, from 50 to 150 feet thick, which skirts the shore from as far north as the Fiume Freddo to as far south as Prajola, a distance of about ten miles. This alluvium, as I afterwards learnt, stretches inland for three or four miles, forming a terrace or platform on which several towns, such as Giarre, are situated. It contains fragments of such rocks as I

of from 100 to 300 feet, have flowed down on each side of the ridge. These newer lavas, which are very similar in composition to the older, are fragmentary, like those of Etna, *on the surface*, or broken up into pieces for a depth of several feet; but no section affords an opportunity of determining whether they contain solid beds in the interior.

Professor SMYTH has advocated VON BUCH's theory of upheaval in reference to the more ancient parts of Teneriffe, but regards the central or modern cone, to which the above-mentioned inclined beds of porphyritic obsidian belong, as a cone of eruption.]

remembered to have seen when I visited Etna in 1828 among the old lavas and dikes of the Val del Bove. Hence I was led to inquire whether these transported masses, some angular, others rounded, the larger ones often more than 5, and in some cases 9 feet in diameter, might not, together with the associated sand and gravel, bear testimony to the gradual excavation by aqueous erosion of that vast crateriform cavity which forms the principal feature of the eastern flank of Etna.

No small portion of the alluvial deposit, particularly where the thickness of the mass and size of the blocks are most conspicuous, lies exactly opposite the Val del Bove, in the low region to which the few torrents which still drain it in the rainy season carry down their tribute of sand and boulders. The area occupied by the old alluvium is accurately laid down on the great map which accompanies Baron S. von Waltershausen's splendid work, now in the course of publication, entitled 'Atlas von Etna,' to which I shall often have occasion to refer in the sequel. A reduced copy of the map accompanying that valuable monograph is given, with the author's kind permission, as one of the illustrations of this memoir (Plate XLIX.). The nature and geological age of the alluvium will be more fully discussed when I treat of the probable origin of the Val del Bove.

Another feature which arrests the geological traveller's attention as he passes along the coast at the base of the great volcano, is a series of terraces which terminate abruptly in escarpments facing eastwards and resembling sea-cliffs. This character in the physical geography of the country prevails throughout the fertile region, extending for more than twenty miles north of the city of Catania and three or more miles west from the sea to a height of 1000 feet and more above it, and is equally observable, whether the country consists of marine tertiary clay with associated basaltic rocks, as at Trezza, Aci Castello and Catira, or is composed of lavas of subaërial origin, as at Aci Reale, or of the alluvium already alluded to, as at S. Leonardello. The ancient cliffs are often from 300 to 600 feet in height; some of them two or three miles inland, others, as in the case of Aci Reale, having their base still washed by the waves.

Reasons will be given in the sequel for concluding that this line of coast has been gradually upraised and made to emerge in comparatively modern times; and it will be shown, among other proofs, that littoral shells of recent marine species are met with here and there on the surface, as high as 40 feet or more above the sea-level, in a fresh state and retaining much of their original colour. A similar upheaval prevailing for a much longer period, and affecting somewhat uniformly considerable areas, has carried upwards the whole of the adjoining land, perhaps the whole mass of Etna and much of the surrounding non-volcanic territory, raising it bodily a thousand or more feet above its former level, and giving rise to those ancient inland cliffs above alluded to.

When we try to determine the relative age of the various geological monuments connected with these movements, we find the task more complicated than where we have simply to deal with rocks of subaqueous origin, such as have been slowly uplifted and made gradually to rise out of the sea. For beside the successive rise and denuda-

tion of the masses once submerged, we have in this instance to allow for the contemporaneous building up above the waters of a great volcano thousands of feet high, as also for the flowing down from it of lava-currents, some of them partially or entirely masking the old inland cliffs, or having reached the coast so as to convert tracts of sea into land. The deltas, moreover, of torrents which have derived nearly all their sand, pebbles, and transported blocks from the volcanic formations of various dates, have in their turn been uplifted, so that the alluvial accumulations before alluded to of comparatively modern date, now constitute terraces terminating in low inland cliffs. It is necessary, therefore, to bear in mind all these and other peculiarities in the physical geography of this region, before we can understand the position of some of the lavas about to be described.]

Highly inclined stony lava of Aci Reale.

The town of Aci Reale*, situated about twelve miles north of Catania (see Map, Plate XLIX.), stands on the top of a cliff, in which a platform, elevated at some points near the town, more than 650 feet above the sea, ends abruptly. The slope of the inclined plane forming the summit of this platform is usually at an angle of three or four degrees, but is occasionally steeper, and is prolonged two or three miles inland. The precipice between the town and the sea is in many parts perpendicular, although a line drawn from the top to the bottom would rarely exceed 45°, and in some parts would only amount to 35°. In the face of the cliff are exposed the truncated edges of those seven lava-currents which were noticed by the Canon RECUPERO in his 'Storia Naturale dell' Etna,' and to which the traveller BRYDONE called attention in England, by stating in one of his 'Letters on the two Sicilies,' that RECUPERO had been able by the aid of these lavas, "to assign a higher antiquity to Mount Etna than had heretofore been ascribed to our planet itself." Dr. CARLO GEMMELLARO assures me that he has verified the accuracy of the Canon's descriptions, especially the fact, that at no less than seven different levels there intervene, between successive currents of lava, red layers either of burnt tuff or of decomposed scoriaceous crusts of lava-currents, which have been baked and reddened by heat, or as Professor BUNSEN would say, by "fumerolic action" superinduced by the incumbent lava. Five of these brick-red bands I saw myself in one vertical section at the Scalazza, a spot of which I shall presently have more to say. They reminded me precisely of the red clays and tuffs which abound in the Island of Madeira, where many subaërial lavas have overflowed the surface in succession, and where there have been sufficient intervals of time between successive eruptions for the decomposition into clay of the crust of each preexisting lava, or where volcanic sand has been showered down from above or washed over the older lava by torrents and floods.

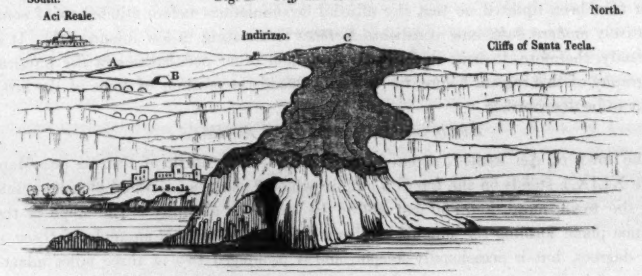
We need not, however, seek illustrations of such a phenomenon in distant regions, since in the suburbs of the neighbouring Catania similar baked and altered soils of a

* When I first examined the cliffs of Aci Reale (October 1857), I was accompanied by a skilful young geologist, Signor GAETANO GIORGIO GEMMELLARO.

red colour are to be seen at the contact of the lava of 1669, with ground which before that year was highly cultivated

The cliff of Aci Reale above mentioned and represented in the accompanying rough sketch (fig. 1), for which I am indebted to the kindness of my friend Dr. CARLO GEMMELLARO, is about 500 feet high. It runs parallel to the sea for some distance north

Fig. 1.—*Cliff and coast at Aci Reale.*

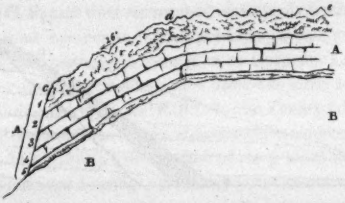


A. Upper part of the road called the Scalazza.
B. Bastione del Tocco.
C. Lava-current which descends the cliff to the Grotto delle Palombe.
D. Grotto delle Palombe.

and south of Aci. Seen from a boat, the lava-currents appear horizontal, because the section is transverse to their dip. They are, however, in reality inclined at angles varying from 4° to 7° seaward. Below the letter A (fig. 1) a zigzag road called the Scalazza, partly built on arches, leads down from the town to the village of La Scala. At the end of the second turn of this road, and about 150 feet below the summit of the platform (B, fig. 1), is a part of the fortification called the Bastione del Tocco, where an indentation occurs in the face of the cliff, probably made originally by the sea at the time when the precipice was undermined by the waves. This indentation affords the geologist a rare opportunity of seeing a longitudinal section of one of the lavas, the uppermost of the whole series at this point, exposed in the direction of its course from west to east. It consists of a powerful current dipping east or towards the sea at angles varying from 23° to 29°, and exposed for a length of 80 feet in the garden of one GIUSEPPE TORRISI. The mass has all the usual characters of an Etnean lava-current, displaying an upper and lower bed of scoriæ (A 1 and 5, fig. 2) with an intermediate stony portion (A 2, 3, 4), which in this instance is more than usually thick and compact. The upper scoriaceous crust (A 1, fig. 2) is about 12 feet thick, below which comes the stony portion (A 2, 3, 4) 20 feet thick, having a dip of from 23° to 29°, and divided into three beds, each about 6 or 7 feet thick, the lowest becoming at its base first cellular, and then vesicular and scoriaceous. The rock is a compact grey dolerite with numerous crystals of felspar, and some of augite with a small quantity of olivine. The

whole of these stony beds (A 2, 3, 4) are divided by joints nearly at right angles to the planes of bedding. The passage from the upper crust or scoriæ to the compact

Fig. 2.—*Section of lava inclined at 23° and 29° at the Bastione del Tocco on the Scalazza of Aci Reale.*



c, d. Section running east and west.
d, e. Section running from south to north, or at right angles to the dip.
A. Uppermost lava-current:—1, scoriaceous crust; 2, 3, 4, compact, stony beds; 5, lower scoriæ.
B. Red or burnt surface of subjacent tuff.

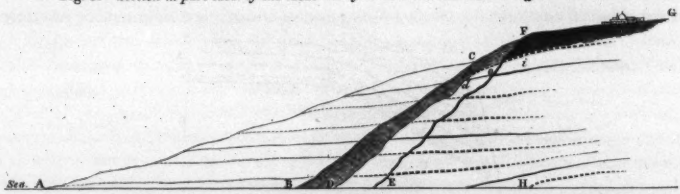
dolerite (A 2) is very abrupt, as is that from the lower part of the stony lava (A 4), where it becomes cellular to A 5, or the underlying scoriæ. This last is about 2 feet thick, and consists of small fragments for the most part agglutinated together. At its contact with the uneven surface of the subjacent tuff (B) it fits into and fills up the depressions several inches deep in that tuff, which is composed at the top of sand and lapilli burnt red for a depth of from 1 to 2 feet. Below this, but not visible at the point of section (fig. 2), is a coherent earthy tuff of fine-grained materials and a light brown colour, without lapilli, and divided somewhat regularly by joints, so as to have a columnar appearance.

[This fine-grained stratum rests on loose volcanic sand of a black colour, containing many heavy blocks of lava, more or less rounded, such as are seen in the beds of torrents which descend from the flanks of Etna. At the time of my second visit to Aci (1858), several of these hard blocks, from 12 to 16 inches in diameter, had just been dug out of the black sand in a vineyard adjoining the Bastione. The whole deposit, including the tuff, resembles the transported materials observable in the wide water-courses which furrow the western slopes and base of Etna. Below the above-mentioned tuff and loose sand is seen another current of lava 40 feet thick, also having red or burnt tuff below it, and below that again there appear, in the face of the cliff on the left hand as we descend the Scalazza, a series of other beds, among which are four lavas, each reposing on red and altered tuffs or soils.]

To return to the inclined dolerite of the Bastione: we have first to consider whether it can possibly have acquired its present dip, averaging about 26°, in consequence of a landslip or any other movement posterior to its original congelation. That it has not done so, is demonstrated by the fact that it is a continuous part of an unbroken and uninterrupted lava-current, the uppermost part of which can be traced for several hundred

yards westwards from F towards G (fig. 3), gradually rising 100 feet or more from the Bastione to near the top of the platform of Aci Reale. The crust of scoriæ is sometimes

Fig. 3.—*Section in part ideal of the lavas and of the ancient and modern cliff at Aci Reale.*



A, B, C. Portion of the lavas and tuffs supposed to have been removed by the sea.
B, C, F, G. Lava-current of the Bastione, of which a portion, B, D, F, C, was afterwards removed by the sea.
E, F. Existing cliff at the Scalazza.
o, *i*. East and west, or longitudinal section seen at the Bastione.
The interrupted lines - - - indicate the brick-red tuffs and soils torrified by the overlying lavas.

(as may be seen at the road-side on the Scalazza close to the Bastione), separated into irregular alternate layers of solid dolerite and beds of loose scoriæ. From the point where the natural section (fig. 2, p. 713, and *o*, *i*, fig. 3) presents itself, this upper crust unites without any break with the mass which we can follow, through gardens, and also in another line up a steep lane, to a point where the dip is gradually reduced to 15°. Still higher up the hill we arrive at the church of Santa Maria, where in the suburbs of Aci Reale, a lava, which I believe to be the same, has a dip of only 9°.

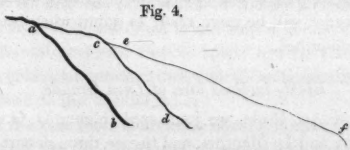
If the red stratum, indicated in fig. 3 by the interrupted line above *o*, *i*, on which the inclined dolerite of the Bastione rests, had consisted simply of a burnt soil derived from the decomposition of an older and subjacent lava, we might have supposed the unusually steep dip of 23° and 29° to have arisen from the accident of the newer current having at this point overflowed the terminal slope of a preexisting lava; for when lavas come to a halt (as is well exemplified by the newest of all the Etnean currents, that of 1852 in the suburbs of Zafarana), they commonly end in a steep wall, 20 and 30 feet or often more in height, and sloping at angles of from 20° to 35°, as represented at H, fig. 3. But this hypothesis is rendered untenable by the fact that the stratum of tuff and lapilli burnt red, is not the disintegrated surface of an underlying lava, but the upper part of a series of strata of tuff and loose black sand containing boulders, deposits such as we find in the wide channels of torrents on the flanks and near the base of Etna.

To explain, therefore, the steep inclination which the surface of the stratum (B, fig. 2, p. 713, and *i*, fig. 3) had acquired before the lava G, F, C, B reached the present site of the Bastione, I think it necessary to suppose that a sea-cliff (D, *d*, *o*, *i*) already existed, the top of the cliff consisting of beds of brown tuff and loose black sand, forming the mass *i* as above described, which as a whole was too incoherent to produce a precipice, but which

might, when the rocks below were undermined, have slid down and formed a slope of from 20° to 30°, as from *d* to *i*, fig. 3. The Bastione lava, after flowing over the platform from G to F and baking the underlying tuff at *i*, *o*, *d*, which it turned red, descended in a cascade to the foot of the old cliff D; but the sea immediately resuming its efforts cut away the new facing of lava B, C, F, and then encroached some yards further into the older rocks from D to E, in the same manner as it had previously swept away the lavas A, B, C, which formed the original eastward prolongation of RECUPERO'S seven currents. After these complicated operations, the Bastione lava itself was made to end abruptly (as at *o*, fig. 3) in the face of the actual precipice E, F. In the Canary Islands, especially on the south-western coast of Palma, I have seen numerous lava-streams of modern date pouring in like manner in black sheets over the face of steep sea-cliffs, at the base of which the waves of the Atlantic are beating. So many years commonly elapse between two successive eruptions, and so many more before a second stream of lava happens to reach precisely the same point of the coast, that the sea has usually time to remove a part of, or all of the new facing of stone which for a season had protected the old cliff. Such inroads, however, of the ocean, though they check the advance of the land, cannot prevent the cliffs from gaining continually in height.

[By referring again to fig 1 (p. 712), the reader will see at and below C a representation of a great current of lava, to which my attention was first drawn by Dr. CARLO GEMMELLARO, whose interpretation of its position relatively to the ancient cliff of Aci I now am prepared to adopt after examining it in 1858. The lava (C) came down from the west or from the higher region of lateral cones over the platform of Aci, and its right margin is to be seen in the northern suburbs of the town at the church of Indirizzo (fig. 1), where its exterior or scoriaceous covering alone is visible. The more stony portions of the crust consist of a dark rock with crystals of felspar. The current, when it reaches the brow of the cliff, may be traced in gardens below C, descending a steep slope at angles of 23° and 28°, yet here and there houses are built on ledges of the rock. The more ancient parts of the cliff occurring south and north of the course of this current, whether on the Aci or Santa Tecla side, have a declivity of 35° and in some places 47°, being on the average 20° steeper than the newer lava. Thus, when viewed in profile from the south, the old cliff is represented by the lines *a*, *b* and *c*, *d* (fig. 4),

Fig. 4.



while the new lava forms the slope *e*, *f*. But no section of the interior of the mass *e*, *f*, much less of its junction with the face of the old buried cliff, is obtainable. Half-way down from *e* to *f* I found the same character in the lava, as above, at *e*. Near the sea,

below *f*, and not far from the Grotto delle Palombe, we see a longitudinal section for the space of 100 feet, the scoriaceous crust being removed by denudation. Here a central stony but not compact layer is laid open to view, 2 or 3 feet thick, with a dip of 25°. On the margin of the sea, we find below the scoriaceous crust, a stony mass, more than 20 feet thick, exposed in a vertical cliff, at the foot of which the waves have excavated a cavern 14 feet high, called the Grotto delle Palombe (D, fig. 1, p. 712), only approachable in a boat. Here the rock is compact and columnar, the erect and often well-shaped pillars being composed of a dark dolerite. Over the cave, in a bed of lava in which many fragments of scoriæ are involved, oblique and irregular prisms appear. Still higher up, a nearly horizontal stratum, 4 feet thick, with a vertically prismatic structure, is observable. As this coast has undergone, as before stated, p. 710, an upward movement in very modern times, it is possible that the lava of Indirizzo and of the Grotto delle Palombe may be ancient enough to have participated in the upheaval, in which case the columnar mass may have been at first submarine, and may have cooled on a gently sloping ledge of rock. We cannot, however, infer its original submergence from the prismatic structure alone, because we have innumerable examples in Auvergne and the Vivarrais of subaërial lavas, in which there are fine ranges of basaltic columns as perfect as any in the Giant's Causeway or Fingal's Cave.

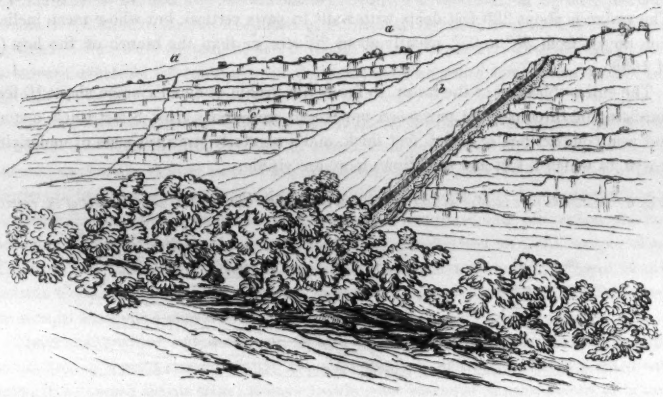
About a mile north of Santa Tecla, and nearly three miles north of Aci Reale, another much more modern lava, namely, that of 1329, is seen descending from the interior or region of lateral cones, and entering the sea at a place where the coast is much less lofty than at Aci, with a breadth, as will be seen by S. von Waltershausen's map, of about a mile. If we reflect on its position, as well as on that of many other lavas of different ages which have thus poured down one after the other over these sea-cliffs while the waves are always eating away the sea margin, the hypothesis above suggested in explanation of the steep slope of the tuff underneath the lava of the Bastione of Aci will not seem far-fetched or improbable. But in whatever manner we may account for that slope, it is undeniable that a mass of compact dolerite, 20 feet thick, exposed to view at the Bastione, has consolidated into compact rock, with a dip of 23°, 26°, and 29°; and had the sea removed as much of the current of the Grotto delle Palombe (or C, fig. 1) as I assume it to have done in the case of Aci at B, E, F, C (fig. 3, p. 714), a similar exhibition of stony beds dipping at angles as great or greater would I believe have been made. But this the reader will be more ready to admit when he has fully considered the section next to be described.

Highly inclined lava of Cava Grande.

From the Scalazza of Aci Reale, we journeyed (Signor G. G. Gemmellaro and I, October 1857) by Giarre and La Macchia, and thence through part of the woody region to the great chestnut, called the "Castagno dei Cento Cavalli," which stands on a tufaceous deposit at a height of more than 2000 feet above the sea. We then went direct to Milo, and in our way fell in with a second fine example of a sheet of modern

lava, in this case of known date, conforming to a very steep slope, and having its internal structure remarkably well displayed. Our bridle-road led us round the head of a deep and narrow gulley, called the Cava Grande (see Maps, Plate XLIX. and L.), the largest of several which furrow this part of the eastern flank of Etna. Looking down the ravine, we saw on the right bank a stratified mass, turned edgeways towards us (*b*, fig. 5),

Fig. 5.—*Highly inclined lava of Cava Grande.*



a, a. Main stream of lava of 1689.
b. Branch of same lava (*c, d*, fig. 6), having a mean inclination of 35°.
c, c'. Right bank of ravine composed of older lavas.

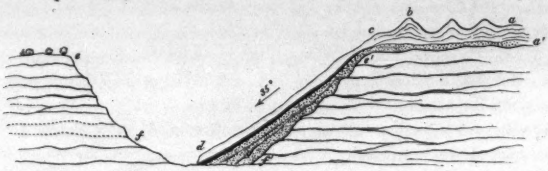
which I thought at first must be a portion of the beds of lava and scoriæ which had once belonged to the upper part of the cliff, and which, having been undermined by the torrent, had slid down the steep bank. But on nearer inspection we ascertained that the inclined mass (*b*, fig. 5) was a branch of *a, a*, or the great current of 1689, which flowed down from the Val del Bove in that year, and cascaded in the manner represented in the annexed drawing (fig. 5), over the right bank of the Cava Grande. The ramification of this current is very accurately laid down in the Map of S. von Waltershausen, copied in Plate L., where the date assigned to it is 1688; but Dr. Giuseppe Gemmellaro in his Map of Etna has given the date as 1689, and he tells me that the lava of the preceding year was confined to the Val del Bove.

For a great part of the year there is no water flowing in the Cava Grande, nevertheless occasional floods have in the course of ages excavated this deep narrow chasm, at the upper end of which we find, what is so common at the head of narrow valleys on the sides of volcanos, a perpendicular precipice, of a horse-shoe form, over which water falls in a cascade, which is gradually cutting its way backwards. [Although the channel was

dry at the time of my last visit (September, 1858), I witnessed several avalanches of sand and stones loosened by the heavy rains of the preceding day, proving to me how great must have been the waste of these cliffs in the course of the 170 years which have elapsed since the lava (*b*) poured over the right bank. The geologist is indebted to such annual waste not only for the section of the lower extremity of the lava, but also for that of its side, as shown in fig. 5, from which great fragments have broken away for a space of about 200 feet in length, many of them still strewed over the slope.] The ravine is about 220 feet deep, with walls in parts vertical, but whose mean inclination ranges from 38° to 65°, usually about 20° steeper than the branch of the lava (*b*) of 1689.

The entire thickness of the latter, so far as it is visible, is on an average about 16 feet, consisting of three parallel parts—an upper and scoriaceous crust 8 feet thick, a stony and very compact bed of rock 5 feet thick, and a regularly stratified mass of underlying scoriæ, of which 3 feet and sometimes more are visible.

Fig. 6.—*Section in part ideal of ancient and modern lavas in the Cava Grande near the head of the ravine.*



a, c. Lava of 1689, with lofty, parallel, east and west ridges.
c, d. Branch of same current descending the right bank of the Cava Grande, and inclined at 35° and higher angles, the dark central portion being compact, the rest scoriaceous.

The annexed section (fig. 6) is supposed to pass through the Cava Grande in a north and south direction, or at right angles to its course, and to intersect not only the newer lava of 1689 (*a*, *c*, *d*), but also the nine or ten older currents of Etna (*e*, *f*, and *e'*, *f'*) which constituted the walls of a ravine before the modern lava poured into it. The old currents alluded to appear horizontal in the diagram, because they are intersected at right angles to their dip. They are in fact inclined at about 7° eastward or towards the sea, each lava being on an average about 10 or 12 feet thick, and separated by fragmentary matter belonging to the top and bottom scoriæ of successive currents, or sometimes by tuff, *i. e.* volcanic sand and mud transported by land-floods or the winds. These partings are about equal in thickness to the solid beds, and exhibit at various heights red or burnt strata, as at *f*, three of them being conspicuous on the left bank.

To return to the branch of the lava of 1689, or *c*, *d*, fig. 6: I have stated that its central portion is quite compact. It contains crystals of felspar, but none of augite, a small quantity of olivine, no iron, and its specific gravity is that of an ordinary trap-rock. It is worthy of notice, that this central inclined layer surpasses greatly in compactness a

large part of the old rocks (*e*, *f*) in the cliffs of the right and left banks. The joints are few, often 9 or 10 feet apart, so that detached fragments of this stone, 9 feet in length and 5 feet high, may be seen strewed over the slope on the left side of *c*, *d*, fig. 6. The demarcation between the stony layer and bottom scoriæ is marked, whereas the passage of the same into the upper scoriæ is more gradual. [The normal thickness of the solid rock is 5 feet, where the inclination is 32° and 35°; but when near the top, as at *e'*, the dip increases to 45° and 47°, the thickness is reduced to one-half, or 2½ feet, just as a stream of water, arriving at a steep part of its channel, increases in speed and diminishes in depth. Yet, when dipping at 47°, it is still not only stony and compact, but there is no breach whatever of continuity in the mass, and no more joints than in the less inclined portion.

The first operation which took place when the lava reached the edge of the ravine, seems to have been the rolling down of scoriæ from the frontal wall of the advancing current, so that the uneven sides of the ravine were levelled, and a sloping talus of loose scoriæ (*g*), for the most part inclined at 32° to 35°, was produced. But near the top, at *e'*, before the old precipice had been reduced to that more moderate inclination, the lava cooled at an angle of 47°, and might probably have consolidated on a still steeper slope. The width of the branch *c*, *d* must exceed 400 feet, and is therefore so great in proportion to its depth, that in a transverse section the central stony layer of 5 feet would be seen to form what might be termed a sheet of lava.

The traveller will at once see, by the state of the surface of this current and by its vegetation, that it is not a current of high antiquity. Except where cultivated or planted with trees, it is covered simply with lichens or with a few scattered shrubs, chiefly of broom. The superficial irregularities of the main current (*a*, *c*), when contrasted with the comparative evenness of the branch *c*, *d*, are very striking, the first inclined at 16° east, the other at 32° and 47° north. Indeed, the height of the parallel ridges, from *a* to *b*, no less than four of which come within a few hundred paces of the Cava Grande, is excessive, as is the steepness of their sides. The ridge *b* is about 40 feet high and 40 wide, its north side, or that towards the Cava Grande, sloping at an angle of 70°, its southern at 35° and 40°; the mineral composition of the concentric layer of scoriaceous lava forming the outer part of the ridge being similar to that of the branch *c*, *d*, fig. 6. The continuity of the branch *c*, *d* with the main current (*a*, *b*), is such as to preclude the supposition of the slightest change of position in *c*, *d* since 1689, when it cascaded into the Cava Grande; and if there were no other section on Mount Etna to illustrate the capability of lava to form, when cooling on a steep slope, a dense and continuous layer of stone, such as would be termed trap in the ordinary language of geologists, this example in the Cava Grande would suffice.]

Structure, aspect, and inclination of the lavas of the great eruption of 1852–53.

From the Cava Grande we went by Milo to Zafarana, and observed at the former place some recent changes which the last great eruption of Etna, that of 1852, had

effected. One branch of the lava, flowing from the Val del Bove, had entered and filled up the bed of a torrent which passed by Milo, and the displaced waters have ever since been seeking a new channel. Just before our arrival (October 1857) they had undermined several houses in the village, and had excavated in a street through which we rode, a gulley 26 feet deep, displaying a section of alluvium of that depth, made up of rolled pebbles of various volcanic rocks. This evidence of torrential action at the height of 2136 French feet above the sea (the height of Milo as measured by S. v. WALTERSHAUSEN), is not without its bearing on questions hereafter to be discussed.

Zafarana, to which we next proceeded, is 1748 feet high. We found the country between it and Milo adorned with woods and vineyards, and furrowed by parallel ravines, reminding me of the barrancos of Madeira or the Canary Islands; but those of Etna are only incipient barrancos, the erosion of deep chasms by running water being checked, as we have seen, by the occasional filling up of water-courses by lavas and by the absorption of rain, by their porous crusts, and by loose volcanic sand showered down far and wide over the mountain.

At Zafarana we spent five days (October 26 to 30, 1857), making daily excursions into the Val del Bove and returning at night. Between the early dawn and 2 o'clock in the afternoon the sky was usually clear, and the sunshine bright, although there were occasionally clouds and even rain in the region of woods and vineyards below. As the mists ascended and enveloped us two or three hours before sunset, it was necessary to secure time for observation by mounting our mules before daybreak. I had visited Zafarana and the Val del Bove in 1828, and retained in my mind a vivid recollection of the leading geographical features of its grand scenery. I was therefore surprised and somewhat disappointed at the prodigious revolution which had taken place in the interval of twenty-nine years, a revolution caused entirely by the eruption of 1852–53, one of unusual magnitude, the violence of which does not seem to have been generally appreciated in Europe, because the destruction of human habitations was small. The lavas poured forth at that period are regarded by Dr. GIUSEPPE GEMMELLARO as having been perhaps the most voluminous of any that have ever been witnessed, or at any rate recorded, by man, with two exceptions, namely,—1st, that which overwhelmed so many villages and part of the city of Catania in 1669, flowing from Nicolosi to the sea; and, 2ndly, the lava-current of Mojo, supposed by some to have occurred in the year 396 before our era, but the date of which is, according to S. v. WALTERSHAUSEN, very uncertain, though its high antiquity is proved by the amount of subsequent fluviatile denudation which has made wide gaps in its massive current.

Narrative of the Eruption of 1852–53.—As I shall have occasion to allude repeatedly to the consolidation at high angles of this lava of 1852, I shall begin by giving some account of the eruption obtained from contemporaneous narratives of the event, or from conversations with eye-witnesses [and among others, the priest of the parish of Zafarana, Signor G. SCIUTO, who in 1858 kindly placed his diary at my disposal].

The three published accounts of the eruption, which were presented to me by their authors, are as follows:—

1st. Sunto del Giornale della eruzione dell' Etna del 1852, del Dottore GIUSEPPE GEMMELLARO. Catania 1853.

2ndly. Sull' eruzione presente dell' Etna di FRANCESCO TORNABENE, Professore di Botanica, &c. Napoli 1852. Parte 1ª e 2da.

3rdly. Relazione della grandiosa eruzione Etnea della notte del 20 al 21 Agosto 1852, di GIUSEPPE ANTONIO MERCURIO. Palermo 1853.

The first of these writers, Dr. GIUSEPPE GEMMELLARO, visited the Val del Bove during the continuance of the eruption, and I had frequent opportunities of profiting by his instructions and courteous explanations of what he saw.

The eruption began in the night of August 20, 1852, by the violent shaking of the central nucleus of Etna. Some travellers who were passing the Piano del Lago, on their way to the Casa Inglese, saw clouds of scoriæ thrown up from the highest crater. The Balzo di Trifoglietto, or the great precipice which forms the head of the Val del Bove, was rent so that in the course of that first night and the next day there were many openings, some accounts say seventeen, from one of which (No. 1 Map, Plate L.), larger than the rest, not far below the Torre del Filosofo, and between the Serra Giannicola Grande and the Serra Giannicola Piccola, scoriæ were ejected. According to some of the narratives, a small quantity of lava issued from this point.

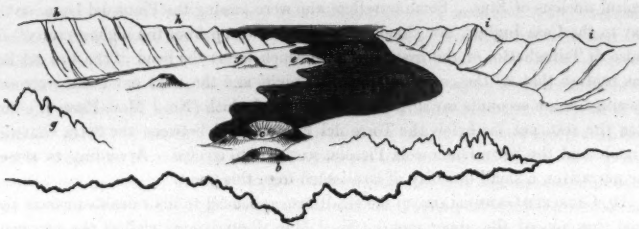
[Dr. GIUSEPPE GEMMELLARO, in the small map appended to his valuable memoir above cited, has placed the upper mouth (No. 1 Map, Plate L.), as well as the two craters Nos. 2 and 3 *ib.*, to the south, instead of to the north of the Serra Giannicola Grande. Having with me in 1858 S. v. WALTERSHAUSEN'S map, which was not published when Dr. G. GEMMELLARO wrote, and my guide, ANGELO CARBONARO of Nicolosi, having accompanied travellers to the mountain on the night of the 21st of August, I was able to ascertain and lay down more exactly the site of these three points, though by no means with trigonometrical accuracy. The two cones and craters (2 and 3) lie north of the eastern extremity or base of the Serra Giannicola Grande. They were thrown up on the line of a great fissure, which opened the day after the eruption began, and are still very conspicuous objects at the head of the Val del Bove, as will be seen by the outline of their forms, given in two sketches in the next page, *b*, *c*, figs. 7 and 8, taken by me September 25, 1858, when, in consequence of heavy rain which had fallen the day before, the fumeroles were so numerous that the cones had almost the appearance of being still in eruption.

The bird's-eye view, fig. 8, obtained by looking down into the Val del Bove from the edge of the precipice, immediately below the Torre del Filosofo, will convey to the reader a tolerably correct idea of the position of the two craters, as seen from above, as also of the course of the lavas issuing from the base of the Centenario, and flowing towards Milo and Zafarana.

Fig. 7.—*Outline of the two cones of* 1852 *near the foot of Giannicola, as seen from the south.*

A. Lower part of Giannicola Grande.
b. Upper cone, No. 2 of Plate L.
c. Lower cone called Centenario, No. 3 of Plate L.
d. Commencement of the current of lava of 1852.

Fig. 8.—*Position of the two cones and of the lava of* 1852–53 *in the Val del Bove, as seen from above.*



a.	Part of Giannicola Grande.	*g.*	Giannicola Piccola.
b, c, d.	Same as in fig. 7.	*h, h.*	Concazze.
e.	Monte Finocchio Inferiore.	*i, i.*	Serra del Solfizio.]
f.	Rocca Musara.		

The inferior and largest of the two cones was named the Centenario, from a centenary fête which the Catanians were then celebrating. It vomited on the 21st of August, and for the sixteen succeeding days, incessant showers of sand, scoriæ and lapilli, with occasionally huge blocks of lava, building up a truncated cone, which became at length about 500 feet high on its eastern side, or the side towards the Val del Bove, and measured nearly 1000 feet diameter at its base. The first day (21st) the lava ran in eight hours to the Dagala dei Zappini (see Map, Plate L.), or about 4000 metres (two and a half English miles in a direct line, according to S. v. WALTERSHAUSEN'S 'Atlas'). On the 22nd it reached the Sciara di Femina Morta, or lava of 1284 (north-east of the Portella, Plate L., now covered by the lava of 1852), and then changing its direction from east to south, flowed towards Zafarana. On the 29th it came near Ballo, and on the 30th and 31st crossed the mouths of the valleys of S. Giacomo and Cava Secca, and continued for five days, scarcely advancing, but menacing Zafarana, till finally it halted within 144 Sicilian canne, or about a quarter of a mile of that town. The whole descent from the base of the Centenario to Zafarana may be about 3500 feet.

Another flood of lava, after passing near the hill called Finocchio Inferiore, approached the suburbs of Milo, while another ramification reached the huts designated Casale on the Map (Plate L.).

During the last days of August and the beginning of September, the 960 inhabitants of Zafarana had been kept in a state of continual terror. On the 2nd of September crowds of people came up from Catania, expecting to see the fiery deluge overwhelm that place. On the same day Dr. GIUSEPPE GEMMELLARO went up from Zafarana into the higher region of the Val del Bove, and obtained a near view of the eruption from the summit of Monte Finocchio Superiore. This hill rocked so violently to and fro with the motion caused by the neighbouring eruption, that his two companions (a guide and muleteer) experienced a sensation like that of sea-sickness. As they looked down from the hill, the whole Val del Bove seemed like a sea of fire, so wide was the expanse of molten matter. For miles they beheld ridges and deep hollows streaked with fire, and emitting a vivid light from numerous rents. Everywhere fragments of loose scoriform rocks were rolling down the steep slopes of the ridges, proving that large portions of the mass were still in motion. The lower cone, No. 3, Plate L., and *c*, figs. 7 and 8, was then between 300 and 400 feet high; explosions like those of artillery were unceasing, and scoriæ were cast up to great heights from the crater.

After a short lull, the intensity of the eruption was again renewed on the 4th of September and continued to the 7th, the column of vapour and sand rising to a vast height, and fresh lava issuing from the base of the new cone, No. 3, so as to overflow the current which had before taken the direction of the Portella di Calanna. The highest crater of Etna sympathized with this new outbreak, sending forth dense clouds of steam. Heavy rain fell on the 26th of September, and the guides of some travellers, who visited the summit of the mountain on that day, reported that the crater was freshly encrusted with a white muddy substance. [This encrustation still continues, October 1858, and has the appearance of a covering of snow at a distance.]

In October fresh lava flowed towards the valley of Calanna, and reaching the head of it, cascaded over the precipice more than 400 feet high, called the Salto della Giumenta. In its descent, says Dr. G. GEMMELLARO, it sounded as if metallic and glassy substances were being broken. It then flowed along the valley below the Salto. Dr. G. GEMMELLARO remarks, that though on this occasion he did not witness the phenomenon, yet at a former period, in 1819, he saw the lava cascade down the same height, and observed that after it had reached the base, and was creeping over the nearly level ground in the valley below, it did not seem to have lost any of its heat or fluidity by the descent.

From the beginning to the end of November and throughout December, the eruption went on, fresh lava running in various directions, and among others, along the base of the Serra del Solfizio and the hill called Zoccolaro, as also in a north-eastern direction towards Finocchio Inferiore, passing by Monte Caliato towards Milo. On the 21st of November, for the second time, lava precipitated itself over the lofty cliff before mentioned, called the Salto della Giumenta, and spreading over the fertile plain at its base,

consumed some of the richest land in Sicily. At the same time changes were observed in the form of the highest cone and crater of Etna. In November some of the lava which issued from below the cone called Centenario, was seen to run in a canal, or beneath an arched crust of solid scoriæ, where the surface had cooled and solidified.

The united breadth of the several lava-streams must have equalled two English miles, if measured in a north and south direction towards the eastern or lower limits of the Val del Bove, and their length was about six miles.

All January, February and March, 1853, intermittent explosions and ejections of scoriæ took place in the Val del Bove, and so late as the 26th of April the lava was still seen piling itself up, one stream over another, in the district of Zapinelli; nor was it till the 27th of May, 1853, more than nine months from the date of its commencement, that this memorable eruption ceased.

In regard to the temperature of the advancing lava, those currents, says Dr. Mercurio, which were fluid (by which he evidently means those which were not greatly encumbered on their surface and sides with scoriæ and stony fragments), radiated so much heat, that trees caught fire and were consumed at the distance of several paces, whilst other currents, which he compares to a heap of moving stones, enveloped the fruit-trees with detached fragments along their borders, so that they were not even scorched. So slowly indeed was the heat conducted through the scoriaceous materials, that some of the trees actually vegetated anew, and burst forth a second time into flower (*ibid.*).

The depth of the lavas varied from 8 to 16 feet, but as successive streams were often piled one over another, they attained double and treble that thickness in some spots, and near the Portella they seemed to me to reach a height of 150 feet.

There can be little doubt that the various apertures (figs. 1, 2, and 3, Plate L.) which emitted lava in August 1852, each of which were formed successively at lower and lower levels, beginning at a great height and not far below the Torre del Filosofo, were all of them in connexion with the axis or highest crater of Etna; for this crater sent forth from time to time, from the commencement of the eruption to near its close, dense clouds of vapour, and occasionally red-hot scoriæ.

Burnt area.—A singular event of peculiar geological interest occurred some weeks after the 27th of May, when to all appearance the flowing of lava had entirely ceased, and when all the currents had become encrusted over with so firm a covering of scoriæ that the inhabitants could walk upon them with safety. Within a certain area (marked as the "burnt area" on the Map, Plate L.), six or seven hundred yards in diameter, and situated between Zafarana and Ballo, all the fruit-trees and vines were struck dead as if by lightning. The ground exhaled no hot gases, and the vegetation did not suffer in the space intervening between the parched-up area and the recent lava, which was only a few hundred yards distant. Dr. Giuseppe Gemmellaro has suggested as the most natural explanation of this phenomenon, that the lava must gradually have made its way through underground passages, until coming beneath the fields alluded to, its heat dried up the roots of the plants. It is well known that vaults and tunnels abound

in many of the modern lavas of Etna, and such empty spaces must sometimes at a subsequent period be unavoidably filled from above with fused matter, which may then solidify under considerable pressure, giving rise to masses of crystalline rock, and offering a perplexing problem to a geologist if he should obtain a section of them without knowing the peculiar conditions under which they originated.

[My friend Mr. HARTUNG, during his late exploration of the Azores (July 1857), observed in Pico, one of the middle islands of that group, a subterranean passage of great length, traversing lava near the port of Cachorro, on the N.N.W. foot of the volcanic cone called the Pico, the highest in the Azores. The lava alluded to is covered with vineyards and orchards, and supports in one place a village, but not exactly where the underground caverns occur. Mr. HARTUNG entered this natural tunnel for several hundred yards, and found in the interior arched caves, some 20, others 30 feet high, occasionally lowering to 3 feet, and afterwards enlarging again. In one place, where the thickness of the roof was slighter than usual, the roots of some fig-trees were seen penetrating through rents, and hanging down into the cavern. Such subterranean cavities, situated only 170 feet above the sea-level, will certainly, says Mr. HARTUNG, be some day flooded by a lava-current from the Peak, in which case the vines and fruit-trees may escape unharmed in spots where the crust of scoriæ (so bad a conductor of heat) is dense, but the fig-trees, whose roots pierce into the caverns, will be killed.]

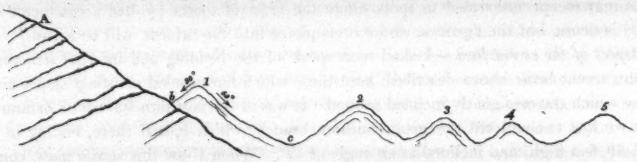
Aspect of the recent lava.—I shall next speak of the bedding and internal structure of the recent lavas above described, both those which have cooled on steep slopes and those which traverse gently inclined ground. It was in the northern suburb of Zafarana that we first encountered the great southern branch, which halted there, ending in a wall 30 feet high, and inclined at an angle of 37°. When I saw this sterile mass, composed externally of fragmentary materials, and listened to the stories told me of the manner in which it had crept slowly over the rich pastures and vineyards, utterly destroying them, together with several habitations, I was forcibly reminded of the like devastations and losses which I had witnessed only seven weeks before, as the effects of a cause as different in its nature as can well be conceived, the Alpine glacier of the valley of Zermatt, where an equally steep mound of rocky fragments, forming the frontal moraine, had been pushed forward by the slow but irresistible pressure of the advancing ice, over green meadows, gardens, and chalets, transforming them at once into a wilderness, irreclaimable for ages.

Passing along the borders of the lava, we soon came to a point where numerous fumeroles bore testimony to the heat still retained in the interior. The white vapours had no peculiar odour, seeming to consist entirely of steam, and we were told that they had been unusually copious for the last four or five days. My companion, Signor GAETANO, suggested that the heavy rains which had fallen a week before might be the cause, the water penetrating to the deeper and hotter parts of the lava, here of unusual thickness, and being thus converted into steam, an opinion which is in the highest degree probable. The scoriaceous surface, kept moist in some places by the warm steam, was verdant

with a moss, named for me by Professor TORNABENE, *Steelina pilifera*. I also found some other portions of the current whitened by a lichen called Stereocaulon, the same which I had seen on modern lava, both in the Canary Islands and on Vesuvius. The natural growth even of a cryptogamous vegetation, although restricted to limited areas, on lava of such recent date, is worthy of notice, and seems to give promise of an early fertility for the future. More than four centuries and a half have left the lava of 1381, at L'Ognina north of Catania, still black and barren, whereas the proprietors have already planted certain tracts of this new current of 1852–53 with broom, which is growing most freely.

Between Zafarana and the lower entrance of the valley of Calanna, called the Portella, we had occasion to pass and repass daily certain portions of the fresh lava, the surface of which displays a series of longitudinal ridges and furrows of extraordinary height and depth, running nearly north and south (N.N.W. and S.S.E.). According to a rough estimate, I found that the crests of the ridges rose from 30 to 70 feet above the bottom of the intervening and parallel depressions, and they varied in number from three to five within the same area, when crossed from east to west. The course of the ridges is similar

Fig. 9.—*Gigantic parallel ridges in the lava of* 1852, *near the Portella of Calanna.*



A. Older inclined lavas and tuffs of Sciuricosimo.
Nos. 1 to 5. Parallel ridges running from N.N.W. to S.S.E., and here supposed to be intersected transversely.

in direction to that of the lava-current. The letter A, fig. 9, represents the escarpment of ancient rocks, called Sciuricosimo (see Map, Plate L.). The ridge No. 1 has a vertical height of 25 feet on its western side, where it slopes at an angle of 30°, and on its eastern side, where in the steep part the slope is 50°, the height above *c* is no less than 70 feet. The ridges (Nos. 2, 3, and 4) are respectively 40, 30, and 25 feet above the intervening depressions. Nearer the Portella, we find some of the flanks of these ridges inclined at 60°; and at certain points, where there had been landslips, they were perpendicular and even overhanging. In such cases, the arrangement consists of, first, one or more irregular outer layers of scoriaceous lava, 2 or 3 feet thick in all, and then, 2ndly, beneath or within that outer crust, several concentric layers of compact rock, each from 6 to 10 inches thick, of the usual Etnean type, exhibiting crystals of felspar in a grey base, with olivine and titaniferous iron, and a few crystals of augite. These interior stony layers we observed in one case inclined at an angle of more than 70°.

Passing up from the Portella (see Map, Plate L.), we came to the hill of Calanna,

between which and the hill of Zoccolaro occurs the great precipice, more than 400 feet high, before mentioned, called the Salto della Giumenta, over which the recent lava twice cascaded, in 1852–53, as already stated, p. 723.

In 1828, I had seen the beautiful valley of Calanna covered with verdant pastures, and bounded by heights adorned with forest trees, so that it formed a blooming portal leading up to the wilder scenery of the more elevated Val del Bove. Now, the once fertile plain was black and desolate, buried under a flood of slaggy lava; and when we ascended from Calanna to the upper platform, I missed still more the picturesque contrast of woodland full of old forest trees by the side of dark strips of sterile scoriæ. The whole region had now become one great monotonous desert, without any relief to the eye except on a clear day, when the lofty precipices forming the head of the magnificent amphitheatre, and crowned with the highest cone of Etna, with its banner of fleecy clouds, were full in sight. The points of highest geological interest, formerly accessible by mules, are now only to be reached on foot by a tedious and circuitous route. There are no longer any cattle in the valley, nothing to justify its original name, scarcely a living creature to be seen for days, though a few goats are still driven up to browse on some shrubby knolls which have escaped the general devastation; and now and then the footprints of a wolf on the sands made us wonder that their prey had not yet wholly failed them.

Aided by an experienced guide, Signor G. G. Gemmellaro and I crossed a part of this new lava-field in as straight a line as we could follow, from a point northwards of the hill of Calanna to the rock called Finocchio Inferiore in the great map of S. von Waltershausen. There was as yet no footpath, not even a goat having passed that way. We found the black scoriaceous crust bent into exceedingly sharp, longitudinal ridges, separated by narrow interspaces, from 20 to 40 feet deep, the sides of each ridge sloping at angles of from 20° to 40°, but seeming at some points to be absolutely vertical. On the crests of each ridge were fragments of scoriform lava, sometimes tabular, and sticking up edgeways, like sheets of broken ice on a Canadian river, where an obstruction or "jam" has stopped the floating masses. More frequently the projecting portions of the superficial crust assumed the forms of gigantic madrepores, or of various animals, such as dogs and deer, or still oftener the heads of elks, with branching horns. The surface often resembled, in all but colour, the descriptions given of coral reefs; and at one moment, when my foot slipped, I had an opportunity of knowing that the stony asperities could tear the flesh of my hands as readily as real corals. The stones on the top and sides of most of the ridges were so loose, that no sooner was one of them set a-rolling, than it started a number of others, until a continuous avalanche poured down into the trough below; but as we had to zigzag our way up each steep ascent, there was little danger of one of us being just under his companion when the torrent came down. Now and then our direct march was arrested by a ridge, rendered impassable by its steepness or the incoherence of the stony fragments forming its crust, which obliged us to make a long circuit, often with our backs turned towards our goal, the hill of Finoc-

chio. The manner in which detached blocks of various shapes and sizes were occasionally poised one upon another, on very narrow ridges, made us marvel that high winds had not blown them down. I climbed up to some of them, to ascertain that they were not soldered on to the mass of scoriæ below; but I found them free to move, and only holding on by the slight inequalities of their surface. At no point could I discover fissures or openings in the scoriaceous crust out of which melted matter might have escaped in a stream so as to fill up the trough below; but pieces of scoriæ had often rolled down in great numbers into the troughs.

At length gaining Finocchio, we found it standing like a rocky islet, submerged up to its middle in lavas of different ages, and with the fresh current of 1852 near its base. The relief afforded to the eye by this oasis was so great, that, although the day was cloudy, the green turf, enlivened by the flowers of a yellow ragwort, looked dazzling by contrast with the dark surrounding desert, and the autumnal crocus (*Colchicum autumnale*), also in full bloom, seemed more than ever beautiful. Returning to the spot where we had left our mules, we at length rode back to Zafarana, over another part of the new lava, where hundreds of fumeroles rose in dense white columns of steam, each of them quite perpendicular, for there was not a breath of wind; and conspicuous from having usually a background of dark lava to show off their graceful forms; so that we could no longer complain, as in our morning's ride, of the featureless monotony of the scene.

The problem ever present to our minds, during the whole of this excursion, was the cause of the curvature of the lava into a series of gigantic wrinkles. In what manner are we to account for these longitudinal and nearly parallel, anticlinal and synclinal ridges and troughs? It is well known that every stream of lava, as soon as its surface and sides have congealed, is encrusted over with a covering of scoriæ and stony fragments, so that it may be said to run in a tunnel, the roof of which is in most cases a flattened arch. The supply of liquid from the source or vent being irregular and intermittent, the current now and then halts for a while, sometimes for hours, days, or weeks, during which time a solid terminal wall is often produced, and one stony layer after another may then be formed gradually within the outer crust by the lava congealing on the sides and roof of the arched tunnel. Such concentric, internal layers having consolidated slowly and under pressure, will often acquire a compact and crystalline texture. But when fresh supplies of hot lava descend from the source, that portion of the current which still remains fluid or viscous being reinforced, may burst through the terminal crust, and the onward progress of the lava recommences. We have already seen, p. 724, that the lava of November 1852 was actually observed, near the foot of the Centenario, to flow in an arched channel, and there were doubtless many other similar lava-ducts having a parallel direction, or running longitudinally in reference to the stream.

[Mr. Scrope has suggested to me, that when fresh molten matter penetrates into such subterranean ducts, they may, by hydrostatic pressure, cause the superincumbent mass to crack and swell up into steeper arches than those originally produced; and I think it probable that such may be the true explanation of the phenomenon, though

before I had witnessed the eruption of Vesuvius in 1858, and had seen a ridge in the act of forming, I speculated on the possibility of the lava of 1852 having been partially forced into its present shape by lateral pressure, caused by the successive flows of lava having been piled one over the other, while the interior of some of the currents first poured out was still viscous or even liquid. The great weight and thickness of the new flows might, I imagined, have given rise, by hydrostatic pressure, to effects like those witnessed where certain railway embankments have been thrown across marshes and peat mosses. In such cases, it is frequently found that as fast as new matter is cast upon them the mounds sink down bodily, while on one or both sides the surface of the bog or morass swells up in one or more parallel undulations. I also referred to the analogous effects of downward pressure, to which my attention had been directed by Dr. GOULD in 1852 at Boston in the United States, where a load of sand and stones, upwards of 900,000 cubic feet in volume, had been thrown into part of an estuary only dry at low water in order to convert it permanently into land. In consequence of the pressure, the adjoining bottom of the estuary, supporting a dense growth of salt-water plants, and previously only just visible at low tide, was pushed gradually upward, in the course of many months, so as to project 5 or 6 feet above high-water mark. The upraised mass was bent into five or six anticlinal folds, and the upper layer of turf having burst open along the crests of the ridges, exposed to view an underlying layer of mud full of recent marine shells*. But I abandoned this explanation of the origin of the Etnean ridges after I had seen similar, though much smaller ones, produced on the flanks of Vesuvius in the manner about to be described.

When I visited that volcano in September 1858, I found that the eruption of the preceding spring had not wholly ceased. Intermittent jets of vapour, illumined by the hot lava of the crater below, were still issuing from the summit, while two minor cones at the western foot of the principal cone, and just below the Observatory, were pouring out continually small rills of lava unaccompanied by any evolution of gases. Some of these rills ran very rapidly near their sources, but when they reached the base of the cone proceeded with extreme slowness. Here I watched the progress of one of them, about 8 feet high, having the form of a steep-sided and narrow ridge, its sharp crest crowned with just such irregular and grotesque-shaped fragments of rock as are seen on the new lavas of the Val del Bove. Its motion was onwards in a straight line, but was only appreciable by great attention. The change of position of the protruding fragments on the crest was only verified by observing their altered relation to other fixed and motionless points of lava just beyond. Viewed in the daytime, the advancing ridge was black, but now and then one of the steep sides was seen to swell out as if composed of viscous matter, and then to crack, disclosing a glowing and white heat within. This opening was soon followed by an avalanche of fragments, black on one side and red-hot on the other, rolling down with a clattering sound to the bottom of the slope. Instead of an escape of lava and levelling up of the ground on one side, or any

* See LYELL's 'Manual of Geology,' p. 136, 5th edit.

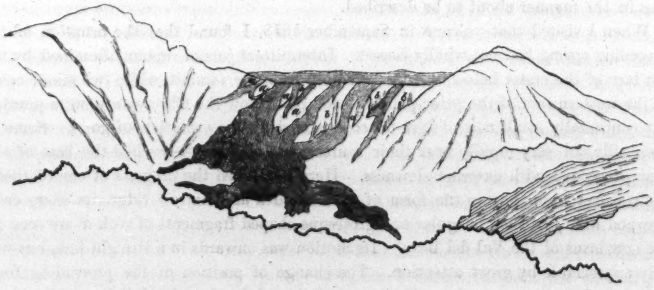
undermining of the ridge, this last retained its full height with its crest or "riggin" unimpaired and its flank even steeper than before. At the same time the most advanced portion of the fluid lava was stealing on beneath a heap of scoriæ which had rolled down from the front or lowest extremity of the ridge, so that the manner in which the foremost part grew in height could not easily be seen.

But although the weight or hydrostatic pressure of fresh loads of melted matter piled upon a current not yet consolidated may rarely if ever give rise to lateral ridges in the manner first suggested at p. 729, it may nevertheless and doubtless does often happen, that this same pressure acts with great force on different parts of the sides and roof of one and the same tunnel, uplifting a viscous or semi-fluid mass, and remodelling the form of the whole current.]

Inclined lava of 1852–53 *at the Salto della Giumenta, or head of the Valley of Calanna.*

We have seen that in the course of the eruption of 1852 above described, the lava descended more than once over the great precipice, above 400 feet high, called the "Salto della Giumenta," which intervenes between the hills of Calanna and Zoccolaro (see Map, Plate L.). The width of the summit of this declivity is, according to S. VON WALTERSHAUSEN's Map, about 200 English feet, but the space over which the lava fell, according to a rough estimate which I made by pacing it, is considerably less. The annexed drawing will give a general idea of the appearance of the dark lava encrusting the

Fig. 10.—*Lava of* 1852 *cascading down the precipice called Salto della Giumenta.*



a. Lava of 1819. *b.* Precipitous outliers of old rock surrounded by recent lava.
c, c. Lava on the level ground in the Valley of Calanna.

steep slope, the spots faintly shaded with vertical lines consisting of ancient rocks, chiefly composed of felspar and hornblende, assuming on decomposition a brown ferruginous colour, and protruding in masses with almost perpendicular sides like the rock in the middle of the Falls of Schaffhausen, or like Goat Island in the Falls of Niagara. Some greyish stripes marked *a* and left white in the drawing represent the lava of 1819, which also went down this same precipice, but which has been since for the most part covered

by the lava of 1852–53. Fortunately at several points the superficial scoriæ, about 3 feet in thickness, has been washed off from both of these lavas by the rain. In the case of that of 1852, we see exposed to view the surface of an underlying stony layer, cellular in part, or somewhat vesicular, but continuous, and containing crystals of felspar and some imperfect ones of augite, with deep-green olivine and great abundance of titaniferous iron. From the stony character of the surface of this bed immediately under the scoriaceous crust, there can be no doubt that 6 or 8 inches lower down it would present a compact texture. The surface of the continuous stony mass alluded to is inclined at angles of 35°, 40°, and 45°, and in one spot at 49°, if not 50°, an angle which my companion obtained with the clinometer, but not without some risk of slipping and being precipitated to the bottom of the precipice. What we had seen in the Cava Grande (p. 717) had prepared us to expect the existence of such a tabular layer of stone beneath the external scoriæ*.

It will be seen by the sketch (fig. 10) that part of the lava of 1852–53, after going down the precipice, continued (at *c*, *c*) its course along the bottom of the nearly level valley, where the slope is not more than 5° or 6°. Here the general depth of the modern current is evidently greater than on the slope, amounting perhaps to 8 feet.

At one point on the declivity of the "Salto" we examined a portion of the lava of 1819, where it had a width of 16 feet, and where the remainder or lateral prolongation of the same was hidden by the lava of 1852. The older current passed under the newer with a corresponding inclination of more than 40°. In such cases a vertical section would exhibit several parallel beds, one over the other, consisting alternately of scoriaceous and stony lava. We estimated the thickness of the lava of 1852–53, on some parts of the declivity (judging by its lateral walls), at about 5½ feet, of which 2 or 2½ may be composed of stony matter. One of the narrowest streams or ramifications was 70 feet wide; so that if the stony portion was seen in a transverse section, say 2 feet thick, it would appear as a thin sheet of matter, the horizontal being to the vertical extension as 30 to 1. Even if the solid layer be twice as thick, the width remaining the same, it would still constitute a tabular mass, having nearly even planes of stratification, and these planes being parallel to the upper and lower scoriæ.

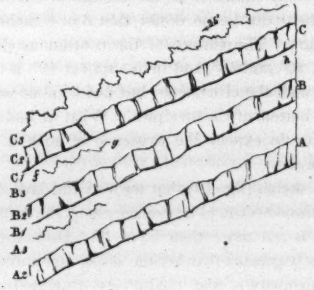
Some geologists imagine that the general absence in the walls of the Val del Bove of extremely irregular surfaces similar to those of recent lava-currents, or exhibiting ridges like those of figs. 6 and 9, pages 718 and 726, furnishes an argument against the analogy of ancient and modern volcanic formations. But there are many reasons why such uneven lines of separation should be rare and exceptional on steep slopes, and should even be obliterated where they have once existed.

In the first place, if the older lavas alluded to were formed, as I believe them to have been, at high inclinations, their surfaces could not originally be very uneven, as we learn from the examples of this "Salto" at Calanna and of the Cava Grande, p. 15, and

* [After re-examining the "Salto" in 1858, I have little to add to the above statement. I myself found a dip of 48° in the exterior of the cascading lava of 1852, not far from the north-east side, or Hill of Calanna.]

others hereafter to be cited. 2ndly. The bottom scoriæ of the newer current is usually so dovetailed into the top scoriæ of the older which it overflows, and so amalgamated with it, that the line of junction, instead of being marked, will usually be obliterated. Let the uppermost line in fig. 11 represent the uneven surface of the most recent of a

Fig. 11.—*Obliteration of the junction-lines of successive lava-streams.*



series of lavas which have been piled one over the other on a slope of 25°. The lava C, the newest of the whole, consists of three parts, namely, C 1 the lower scoriæ, C 2 the central stony portion, and C 3 the upper scoriæ. It will be seen that the bed last mentioned (C 3), although extremely irregular at top, is much less so at bottom, where it passes somewhat suddenly into the stony layer C 2; and again, the latter passes still more abruptly from the solid to the scoriaceous form into C 1, in which the upper plane of stratification is tolerably even. As this lower bed of scoriæ (C 1) had to adapt itself to all the superficial inequalities of the antecedent lava B 3, it might have been expected to afford a junction-line at its base as uneven as the dotted line *f*, *g*; but no such line occurs in nature, because, in the first place, the two lavas B and C following each other next in order of time are usually of similar composition, and the bottom scoriæ of the newer blends into a uniform mass with the upper scoriæ of the older current, so that we cannot discover (as between *g*, *h*) where one ends and the other begins. If the heat of C 1 be sufficient to reduce some part of B 3 to a state of fusion or semifusion, it will be still more difficult to tell which is which. If the overflowing lava moves rapidly, it can scarcely fail to exert a certain amount of friction on the bottom, so as to abrade and level down such asperities as occur on the top of C 3, and which originally belonged to the surface of B 3. But if the lava moves slowly, as it sometimes does even down a steep cone, then another levelling operation comes into play, one which I witnessed during the eruption of Vesuvius, on October 14, 1857, in the Atrio del Cavallo. The lava had been flowing for more than two days, and had gone down from the margin of the great crater to its base, and was there proceeding at a leisurely pace over more even ground. So slight was the motion, that the mass seemed stationary, till after watching it for a

few minutes, we saw fragments detach themselves and roll down the steep-fronted terminal wall, and not stop till they were far in advance of the main body of the current. Such blocks would soon level up any depression that might exist in the superficial crust of an older lava, and would also tend to assimilate in character the component parts of the upper and lower scoriæ. Passages of this kind of the top of one lava-stream into the similarly constituted base of that next above it, are conspicuous not only in the structure of Etna, but in certain sets of lavas in Madeira and in the island of Palma in the Canaries, where the flows of melted matter seem to have followed each other at intervals of time too brief to allow of the production of soils by decomposition, and where consequently no burnt clays of a red colour mark the boundary lines between successive lavas. If, however, a great interval occurs before a fresh current takes the same direction, other causes may come into play to obliterate the superficial roughness of the exterior of an older stream. Thus, for example, showers of comminuted scoriæ drifted by the wind, spreading usually over wider areas than lavas, may fill up hollows; floods of water charged with sand may do the same; the action of the sun, rain, frost, and vegetation causing the disintegration of rocks, may combine to make the successive planes of stratification more even and parallel than at first, though it is true that in most of these cases the red or burnt tuffs would betray the lines of separation.

FRANK INSTITUTE LIBRARY

[*Highly inclined stony lava of modern date in the Cava Secca near Zafarana.*

As the fact of lava being converted into a continuous stony mass when it cools on steep slopes will perhaps be said, even if admitted, to be the exception, it will be desirable to multiply examples in order to show that it is in truth the rule. By reference to S. von Waltershausen's Map, Plate L., the reader will see the position of a narrow valley, about 300 feet or more deep, called the Cava Secca, about a mile W.N.W. of Zafarana. The lavas, scoriæ, and tuffs intersected by this ravine, are many of them among the oldest exposed to view on Mount Etna, and are inclined to the S.E., as are those in the neighbouring valley of S. Giacomo. Near the lower termination of the ravine, at the point *a* on the annexed Map, Plate L., on a steep slope above the right bank of the torrent, a comparatively modern lava is seen, which has descended, subsequently to the excavation of the whole valley, so as to overflow the edges of the older strata, which are inclined in quite a different direction. The side wall of this modern current has been undermined and partially removed by aqueous erosion, just as it has in the case of the lava of 1689 in the Cava Grande before described, p. 717. The section here also shows a dip of 35° N.E., both for the crust of scoriæ 2½ feet thick, and for the central stony layer of about the same thickness. The lower scoriæ are also exposed to view for a depth of 3 feet, and sometimes more. The stony stratum is somewhat porous, yet its specific gravity is no less than 2·554 when first plunged into water, or before any air-bubbles have had time to escape from its inner cells. Many crystals of felspar and a small quantity of olivine are visible in the rock. I observed this modern inclined lava on the right side of the steep mule-path which leads up from the Cava Secca to a plat-

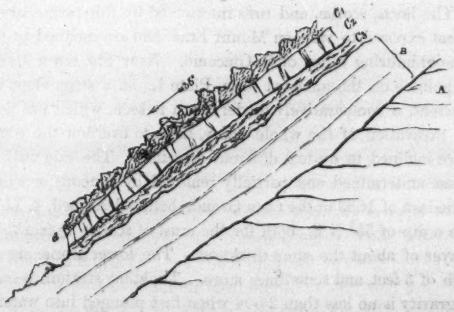
form, by which one may ascend to the flanks and summit of Zoccolaro. The best section occurs at the height of about 60 feet above the bottom of the ravine, opposite a dike which traverses the older lavas on the left or north side of the Cava Secca. The inclination of the lava augments higher up the slope to 40°, and the stony layer decreases to a thickness of 6 inches; but this occurs very near the edge, and it is probably thicker in the middle of the current, which is at least 130 feet wide. At the same place the lower scoriæ are 3 feet thick, and are seen to rest on a red, burnt tuff. On approaching the top of the pass, there is no longer any lateral section of the inclined lava to be seen, for it is there overflowed for a considerable space by a more modern current, viz. that of 1792, the course of which is laid down in S. VON WALTERSHAUSEN'S map (see Plate XLIX.).

The Cava Secca, therefore, affords us an instance of a lava having a central continuous layer as compact as are most of the beds of older date in the Val del Bove, and that layer is inclined at angles of 26°, 30°, and 40°, and is partially covered by a newer lava (that of 1792) in one part of its course, where both currents slope at an angle of 26°.

Steeply inclined compact lava of modern date below the Cisterna (*b*, Map, Plate L.).

The next remarkable instance of a steeply inclined continuous sheet of compact modern lava to which I shall advert, occurs at a point 5000 feet higher than that last mentioned, or near the top of the great precipice at the head of the Val del Bove, not far below the Cisterna. Its lower termination may be seen just above that upper part of the Serra Giannicola to which S. VON WALTERSHAUSEN has given the name of Teatro Piccolo (at the point *b*, Map, Plate L.). Its dip is between 30° and 35° East, and in some parts 38°;

Fig. 12.—*Modern inclined lava between the Cisterna and the Teatro Piccolo, or upper part of Giannicola* (see *b*, Map, Plate L.).



its upper crust of scoriæ (C 1, fig. 12) is about 5 feet, the central stony mass (C 2) 7 feet, and the lower scoriæ (C 3) 7 feet thick. The whole is finely exposed to view, the rain and melted snow having washed away the subjacent scoriæ from both sides of the current,

which is 50 feet broad, so as to undermine the incumbent stony bed, and cause a vertical, or here and there a more than vertical section, for the stony layer occasionally overhangs 4 or 5 feet. The lower scoriæ are divided into distinct strata, and contain masses of ropy lava and volcanic bombs. The solid bed (C 2) is usually very compact, and although in parts vesicular, is on the whole more stony than the average of the older lavas of the Val del Bove, or of the precipice called Balzo del Trifoglietto. The rock consists, like so many of the modern lavas of Etna, of a dark-coloured base, in which are many crystals of felspar and some of olivine. Its specific gravity is 2·785.

At the lower end (*d*), where a transverse section is obtained in consequence of fragments of the terminal crust having fallen down, we find the whole thickness of the mass reduced to 8 feet, the top scoriæ (C 1) being from 3 to 4 feet thick, below which is the usual stony bed, here of a bluish colour, from 1 to 2 feet thick, and then the lower scoriæ. At the same point (*d*), I observed from below the current C another antecedent lava (B) with a powerful upper crust of scoriæ emerging with a like steep dip. There may possibly be some other conformably inclined modern lavas between B and A, which last represents the nearly horizontal older rocks, which in this part of the precipice we know from numerous sections dip gently to the south and south-east.

For several hundred yards down the face of the precipice I ascertained the continuity of the current (C, fig. 12), but at one point I found that the entire mass had been rent, probably by an earthquake, in a direction at right angles to the course of the lava, so that an open fissure 2 feet or more wide now discloses its internal structure, showing that the stony sheet of rock in the centre is persistent in a transverse as well as in a longitudinal direction, affording us an opportunity of determining that it does not, like some narrow lava-streams on a steep slope, sink in the middle, the centre being lower than the sides, as if the lava had run out and caused the crust to fall in. The open rent may imply the sliding down of a portion of the mass at the time of the fracture; indeed I could not look at the dip of this massive current (C), especially its central compact layer, without wondering that the whole has not, during the reiterated shocks to which this part of the mountain is subject, been hurled down into the valley below.]

Many geologists, on beholding from a distance several of these narrow strings or rills of molten matter congealed on the surface of a great talus of sand and scoriæ like that below the Cisterna, may imagine that a cross section could never present to them any appearances analogous to those which we witness in the Val del Bove or in the Atrio del

Fig. 13.—*Appearance in a cross section of two juxtaposed narrow streams of lava.*

Cavallo. But we must remember that the lava above described is 50 feet wide, and if the solid layer be 6½ feet thick, it would be like *a* in the accompanying diagram (fig. 13); and if another similar current should flow down by its side, so that the outer and lateral

scoriæ of each should touch and join in the middle of the section, then *b* would seem to be a prolongation of *a* with merely one of those slight breaks or thinnings out and resumptions of beds with which we are familiar.

I may observe in concluding this subject, that if there be cases (though I did not happen to see one on Mount Etna) where the melted matter has run out from the interior of a stream of lava which has descended a steep slope, so as to cause the superficial crust, together with the solid central layer, to fall and cover in separate pieces the floor of the arched tunnel, this fact would not favour the notion of those who question the analogy of ancient and modern formations in volcanic mountains. The result of the collapse would be simply this, that a stratum of fragmentary and scoriaceous materials of unusual thickness would be seen in the area of the downfall.

Highly inclined modern lava near the Montagnuola.

In the Map of the Val del Bove (Plate L.), the position of the cone called the Montagnuola will be seen. The summit of the steep escarpment immediately below and to the east of it is called the Schiena del Asino. In order to pass from the Val del Bove to the upper region of Etna, we ascended this precipice, more than 2000 feet high, observing the edges of a vast series of ancient volcanic rocks, some crystalline but mostly fragmentary, which dipped to the south-west or inwards, and away from the Val del Bove. At some period since the formation of this great escarpment, and consequently since the origin of the Val del Bove (of which it forms the southern boundary), a lava of unknown date, but evidently from its external characters not very ancient, has poured over the brow or upper margin of the cliff, and running down the slope has covered the outcropping edges of the older lavas and scoriæ. As so often happens where the slope is great, the interior of this current is laid open at its side by the waste, from atmospheric causes, of its scoriaceous crust. Its thickness is 20 feet where it commences its descent, on ground inclined at an angle of 30°, and where the declivity augments to about 35°, the thickness diminishes to about 15 feet.

Here as elsewhere, there is an upper and a lower scoriaceous mass, but somewhat more than half of the whole consists of stony lava, more or less vesicular. We have in this case therefore a solid layer, varying from 8 to more than 10 feet in depth, the thickest seen by us at so high an angle. The current, after flowing down a few hundred yards, seems to have been exhausted, and is for the last few yards of its course broken up into detached and more or less scoriaceous fragments.

Leaving the Val del Bove, we then examined some sections afforded by the channels of torrents, dry at the end of October, which here and there have eaten into the flank of the great cone of Etna, between the Schiena del Asino and the town of Nicolosi. We had not gone far from the "Casa del Vescovo" (sometimes called the Casa delle Nevi), before we saw in one of the watercourses alluded to, a lava dipping at various angles between 26° and 29°, and having a thickness of between 5 and 6 feet. As usual, there was a thin stony layer forming the core or central part. A mile or more further down we

found a dry gulley, evidently excavated by water, 30 feet deep, in which many lavas were intersected having irregular dips, as if, when they flowed into this hollow, the shape of the ground had been repeatedly altered by showers of sand and lapilli, and sometimes by aqueous erosion. Occasionally the angle of dip amounted to 20° or even 28°. The stony beds scarcely ever exceeded 2½ feet in thickness, but were often very compact. All these are of unknown date, but they cannot be of high antiquity, since on this southern slope, where eruptions have been so frequent in historical times, they constitute the outermost integuments of Etna.

If it did not appear to me superfluous, I could enumerate other instances of stony layers which have congealed on slopes of from 10° to 15°, and even higher angles in other parts of the great volcano; but the cases already cited will establish, as a rule, the fact that lava is capable of solidifying and forming stony and continuous layers on slopes even steeper than those on which loose cinders and lapilli can settle. These last may accumulate at an angle of 40°, or even more, for I have seen scoriæ settle on a slope of 42° before my eyes in the recent cone built up in October and November 1857, within the crater of Vesuvius; but in this instance the lava was in a state of semi-fusion when it fell, and the separate fragments may have been soldered together.

Recapitulation.

I will now briefly sum up some of the leading conclusions to which we have been led by the facts described in the foregoing pages, or first part of this memoir.

1st. Lavas which consolidate on steep slopes at angles varying from 15° to 40°, do not consist of a confused mass of scoriæ or of fragmentary matter, but of distinct parts, namely, an upper and lower mass of scoriæ, with an intermediate stony layer.

2ndly. The core or central portion forms a tabular and continuous sheet of compact stone parallel to the overlying and underlying scoriaceous formations, and usually passing somewhat abruptly into them.

3rdly. The lower mass of scoriæ, where the slope is very steep, is more commonly divided into distinct strata than the upper crust.

4thly. There is usually a greater evenness and parallelism of the beds where lavas have congealed at high angles, than where they have consolidated on more gently sloping ground.

5thly. When successive streams of lava have flowed one over the other down steep slopes, the line of junction between the lower scoriæ of one current and the upper crust of the antecedent one is often obliterated.

PART II.

ON THE STRUCTURE AND POSITION OF THE OLDER VOLCANIC ROCKS OF MOUNT ETNA, AS SEEN IN THE VAL DEL BOVE, AND ON THE PROOFS OF A DOUBLE AXIS OF ERUPTION.

It is now time to inquire into the structure of what has been called the nucleus of Etna, sections of which are seen in the cliffs which wall in the Val del Bove on three sides. How far do the mineral characters, and inclination of the volcanic masses composing that nucleus, imply that they were erupted from one or more central craters, and arranged from the first in a conical form; or how far can it be maintained, on the contrary, that they were originally horizontal, or nearly so, and were then, as the advocates of the Elevation-crater hypothesis contend, brought into their present position by movements of upheaval?

Proofs of a double axis.—Cones of Trifoglietto and of Mongibello.

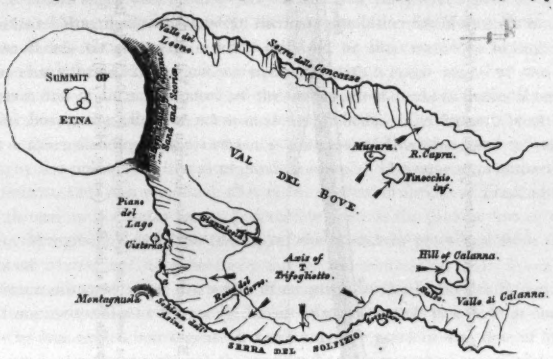
I was aware, from my examination of the great valley on the eastern flank of Etna in 1828, that the beds seen both in the north and south escarpment dip away from the valley; but in that year I had not time to satisfy myself in what direction they were inclined in the lofty western escarpment, at the upper end of the great amphitheatre and below the highest part of Etna. I had observed, as HOFFMANN and others did after me, that there were large amorphous rocks at the foot of the Serra Giannicola in which no stratification is discernible, and which consist in great part of innumerable dikes, some of very large dimensions, penetrating tuffs and agglomerates, the latter so altered by the intrusive matter, that the only divisional planes to be seen are such as are parallel to the walls of the dikes. But on this occasion (October 1857), I found masses of considerable thickness, not far above the base of the Serra Giannicola, distinctly stratified. The rocks alluded to consist of alternations of trachyte and trachytic agglomerate in beds of variable thickness, dipping at angles of from 20° to 28° to the north-west, or towards the central axis of Etna, that axis being about three miles distant in a horizontal direction.

My companion, Signor G. G. GEMMELLARO, had become well acquainted during previous visits with this fact of a northerly dip in the Giannicola beds, which was, I believe, first discovered by Baron S. VON WALTERSHAUSEN; for I learnt on my return to England that it had long been known to him, although not as yet published in his 'Atlas,' the fifth and sixth Numbers of which had not appeared in 1857. I was the more struck with the discovery, from having on the same day observed that the beds in the lower half of Zoccolaro (see Map, fig. 14), which are directly opposite, or about two miles to the S.E., and very similar in colour and mineral composition, dip in a contrary direction, or to the S.E., while those at the foot of the Montagnuola, as well as those between it and the Giannicola, are inclined to the S.W.

I knew, from what I had seen of Etna in 1828, that in the outlying and isolated rocks

of Finocchio and Musara near the middle and northern side of the Val del Bove, and in those of the northern escarpment, the dips were north-easterly, and I now therefore came to the conclusion that there must have been an ancient centre of eruption

Fig. 14.—*Map of the Val del Bove, showing the dip of the beds away from the axis of Trifoglietto.*



in that part of the Val del Bove called the Piano di Trifoglietto, at a point about halfway between the Serra Giannicola and the hill of Zoccolaro, which I proposed to my companion to call the axis or cone of Trifoglietto. At the same time I sketched out an ideal section (see fig. 15), which I afterwards reduced to a true scale, by aid of that given by M. ABICH in fig. 2, pl. 9 of his 'Illustrative Views of Vesuvius and Etna.'

I had seen, during my ascent to the summit of Etna in 1828, that the beds in the Cisterna, more than 3000 feet above the base of the Serra Giannicola and near the edge of the elevated platform called the Piano del Lago, have a gentle dip of about 6° in nearly an opposite direction. I therefore now inferred that Etna must have had at one period a double axis, or two points of permanent eruption, like some of the great volcanos of Java described by JUNGHUHN*, and that there may have been a saddle as that author terms it, or as I propose to call it, an *intercolline*† space between the two cones (as

* Some of these Javanese cones are nearly comparable in size to Etna, and have had two or more centres of eruption. One in particular called Gede may be cited, in which one regular cone, sloping on some of its sides at an angle of 30°, is truncated like Etna and is 9326 feet high; while the other twin cone, Panggerango, somewhat less lofty, has suffered much waste, being cut into on one of its sides by a deep valley comparable to the Val del Bove. The saddle connecting the two mountains is 7870 feet high.—JUNGHUHN'S 'Java,' vol. i.

† In volcanic regions of subaërial origin there are valleys not formed by aqueous erosion, nor by subsidence, nor by anticlinal or synclinal flexures, but simply by the building up on two or more sides of volcanic hills or chains of hills. Mr. HARTUNG and I found many such valleys or spaces in Madeira, and we found it very convenient to have a technical term for them, such as *intercolline*.

Fig. 15.—*Ideal section of Mount Etna, from West 20° N. to East 20° S., to illustrate the theory of a double axis of eruption.*

A. Axis of Mongibello.

B. Axis of Trifoglietto.

d e and *b' i d*. Older lavas, chiefly trachytic.

c o and *d f*. Lavas, chiefly doleritic, poured out from A after the axis or focus B was spent, and before the origin of the Val del Bove.

f g. Scoriæ and lavas of later date than the Val del Bove.

h i k. Val del Bove. The faint lines represent the missing rocks.

N.B. In the section between *i* and *k*, it will be seen that the beds at the base, or near *i*, dip steeply away from the Val del Bove, those in the middle, or below *k*, are horizontal, and those at top, or at *k*, dip gently towards the Val del Bove (see pp. 741 and 742).

L. Older Tertiary and Secondary rocks, chiefly sandstones.

between *c* and *d*, fig. 15), a space gradually filled up by lavas and fragmentary matter, the stratification of which would be occasionally horizontal, and always much less inclined than that formed where two cones have not mutually interfered with each other's regular growth. If, then, we name one of the two centres the axis of Trifoglietto, as before suggested, we may call the other, or the present great centre of activity, the axis of Mongibello, the modern Sicilian appellation for Mount Etna.

The late MARIO GEMMELLARO is cited by M. E. DE BEAUMONT* as having first suggested the idea "that Etna was not a simple cone with a single axis, but was made up of two cones, one of them composed of the more ancient rocks (namely, those seen in the Val del Bove), the other of more modern products. The former, he observed, is placed at a short distance to the east (un peu à l'est) of the other, and is not entirely embraced by the products of the more modern cone." The same experienced observer (MARIO GEMMELLARO) first remarked, that in the modern eruptions of Etna, when lateral cones are thrown up in a linear series, they radiate towards the present crater (or towards the axis of Mongibello), as if the rending of the mountain proceeded from that great central focus.

The former existence of an old centre of eruption in the Piano del Trifoglietto, was inferred from independent evidence by S. VON WALTERSHAUSEN†, *i. e.* from observations first made by him on the convergence towards a middle point in that area of thirteen or more dikes of greenstone visible in the surrounding escarpments, one of them of enormous dimensions, or 70 feet in width. The same geologist, after minutely scrutinizing the structure of those rocks which project like gigantic buttresses from cliffs 2000 and 3000 feet high between the Giannicola and the Rocca del Corvo (including, therefore, the cliffs below the Montagnuola), ascertained that while the beds dip at high angles inwards or towards the escarpment (*i. e.* away from the Val del Bove), in the lower half of the precipices they become horizontal in the middle portion, and towards the summit dip as if they were sloping away from some other point near the present great centre of Mongibello. He found in the rocks called by him Teatro Piccolo and Teatro Grande (see Map, Plate L.), above the base of the Serra Giannicola, where I noticed the steep north-west dip of the trachytic formations, a nearly horizontal stratification in beds intersected by a multitude of vertical dikes.

Signor G. G. GEMMELLARO and I had an opportunity in 1857 of verifying these observations, so far as regards the steep south-west dip of the beds in the lower half of the cliffs below the Montagnuola; and when we looked down from the top of the precipice, called in S. v. WALTERSHAUSEN's map the Schiena del Asino, we saw the unconformable inclination of the superior doleritic lavas, which is well expressed in plate 7 of 'The Atlas of Etna.' We were also struck with the obvious convergence of a multitude of vertical dikes, in the precipices below the Montagnuola and in the Balzo di Trifoglietto, towards the present centre or axis of Mongibello. The whole of these phenomena,—the change of dip in the inferior, medial, and uppermost beds of the Giannicola, the

* Recherches sur l'Etna, p. 124.

† Atlas, V. and VI.

corresponding unconformability of the formations in the cliffs below the Montagnuola (in the rocks called by S. v. WALTERSHAUSEN Vavalaci, Intermedia and Cuvigghiuni), the convergence of countless doleritic and other dikes towards the axis of Mongibello, as well as of the thirteen or more greenstone dikes radiating to the centre of Trifoglietto,—all become explicable as soon as we admit the theory of a double axis. We may assume the existence at an early period of two permanent centres of eruption (whether contemporaneous, like Kilauea and the summit crater of Mount Loa in Owhyhee, or successive, like Somma and Vesuvius), and at a later period the complete ascendency of what is now the principal focus, that of Mongibello, which continues in full vigour, while that of Trifoglietto has long been spent. The latter may have been always a subordinate vent, communicating at a great depth with the main chimney, which may never have materially shifted its position from the first.

It would clearly be unsafe to assume, because the upper part of Mongibello is newer than the entire cone of Trifoglietto, that therefore the latter is the more ancient volcano of the two. What is now the great cone may have attained half or two-thirds of its actual height (from A to *c*, fig. 15, p. 740), and may possibly have been a trachytic mountain before the focus of Trifoglietto came into play. The magnitude and volume of what is now the principal cone, having its centre situated at the distance of three miles from the axis of Trifoglietto (and therefore rather more than "un peu à l'est"), imply that at that point (the axis of Mongibello), throughout longer periods of time than anywhere else, the expansive gases and rivers of melted stone have found their freest and most copious discharge. But as we have no sections to enable us to determine the relative antiquity of the two foci, it would be unprofitable to enter more at length into a discussion on the point *.

[During my third visit to Etna in 1858, I had opportunities of corroborating the observations of S. v. WALTERSHAUSEN respecting the dip of the successive lavas, scoriæ, and tuffs in the Giannicola and in the other great precipices under the Montagnuola. For this purpose I made two descents, one after sleeping at the Casa Inglese from the margin of the Piano del Lago to the base of the Giannicola, and another from the Montagnuola, by Cuvigghiuni, Rocca Intermedia and Vavalaci to the base of the same cliffs near the Rocca del Corvo. The steep inward inclination of the older or inferior beds near the foot of each great cliff is precisely as described by S. v. WALTERSHAUSEN, and just the reverse of the direction we should have anticipated had the highest part of the mountain or the axis of Mongibello been a great centre of upheaval. Midway in one of these lofty cliffs (in the Teatro Grande) I met with a mass perfectly horizontal, consisting of compact rock, 40 feet thick, with vertical columns, yet having an upper crust of scoriæ as well as a lower scoriaceous substratum, in a word, having all the characters of a modern current like that of 1669 at Catania, and like it resting on a red band of burnt tuff. Nothing

* [Since the above was written, I have received (February 1859) Part VII. of S. VON WALTERSHAUSEN's 'Atlas,' in which I observe the cone of Trifoglietto (or G of pl. 24) is supposed to be the oldest part of Etna. It is certainly the oldest visible part, but I see no reason for retracting the views above set forth.]

can be more striking than the absence here, deep in the internal framework of Etna, of all disturbance, just where it ought to have been most manifest, had there been any truth in the upheaval theory; since as we climb up, we are always approaching nearer to the great central axis or highest cone. Lastly, I found a south-easterly dip at angles varying from 7° to 15° in the upper mass, 800 or 1000 feet thick, composed of old lavas and beds of fragmentary matter below the Torre del Filosofo and Cisterna, a state of things irreconcileable, so far as I can see, with any hypothesis save that of a double axis, as above mentioned*.

It is right, however, to mention in this place, that at the upper edge of the precipice under the Montagnuola I observed a slight northerly dip in certain tuffs and lavas, as shown at *c*, fig. 16. This dip I ascertained not only on close inspection, but on viewing them from a distance of nine miles east, or near Bongiardo. They appear to be a continuation of those beds which are seen below the Cisterna at *b*, *a*, but as the natural sections are not complete we cannot prove their prolongation. Such an exceptional inclination *towards* the axis of Mongibello may suggest the idea of an independent centre of eruption at or near the site of the Montagnuola, or if the beds belong to the same system as *a*, *b*, they may have been slightly tilted by movements which accompanied the two great eruptions to which the older and newer craters and cones of the Montagnuola owe their origin. That the older of these cones was due to eruption as well as the newer, is a conclusion to which I arrived after exploring it in 1858, and Signor G. G. Gemmellaro tells me that since I was there he has visited it and has come to the same opinion. It must at least be admitted, that, had the steep dips in the older of the two cones been due to upheaval, as some have suggested, the beds in the great escarpment at

Fig. 16.—*Outline of eastern summit of Etna with dip of some of the uppermost beds, as seen from near Bongiardo, about nine miles east of the Montagnuola.*

c. Same with northerly dip.

a, *b*. Lavas and scoriæ with south-south-easterly dip.

* I had the pleasure of receiving a letter, dated March 3, 1858, from M. Abich, full of valuable drawings, illustrative of the structure of Etna, which has been published in the 15th vol. p. 117, of the Geological Society's Quarterly Journal for 1859. Among other sections, that distinguished geologist has given one (fig. 6, p. 121, *ibid.*) to show the "almost horizontal position" of the beds high up or in the middle of the precipice of the Serra Giannicola observed by him in 1834. He also speaks of a double axis of Etna, the older one to the east of the present centre, but he treats the subject too briefly to enable me to judge how far his views coincide with those set forth in fig. 15, p. 38.

c, fig. 16, and those immediately below in the same cliff exposed in Cuvigghiuni and other rocky promontories, could not have retained the undisturbed and nearly horizontal position which they now enjoy.]

Comparison of the twofold axis of Etna with that of Madeira.

The analogous structure of the island of Madeira, where there is also a twofold axis of eruption, encourages me to believe that the mode of origin above ascribed to Mount Etna is correct. My fellow-traveller, Mr. HARTUNG, and I found in 1853–54 that the lavas have flowed in Madeira chiefly from one main axis or chain of volcanic vents, thirty miles in length, and have overwhelmed the materials eructed from a shorter chain which runs parallel to the other. In the case of the Sicilian Mountain, we have a larger cone overwhelming and burying a smaller one; whereas in the case of the Atlantic island, we have a linear series of volcanic cones, rising at some points to a height of 6000 feet, whence lava and scoriæ have been poured, which have not only filled up the intercolline space, but have so overtopped the secondary chain, as to bury it under a stratified mass 2000 feet in thickness. In both cases there is a difference in the mineral composition of the older and newer lavas, although the order of their relative age is reversed, the trachytic lavas in Madeira being the more modern of the two. In both volcanic districts there is a deep crateriform valley, which to a certain extent cuts through the products of the two axes, for such is the celebrated Curral in Madeira, 4000 feet deep towards its upper extremity and 3000 feet deep, where it intersects the secondary chain at a distance of two miles from the main axis. Nor does the analogy end here; for in the same manner as we see on the west side of Mount Etna towards Bronte (see fig. 15, p. 740), where no lateral cone like that of Trifoglietto interfered with the regular growth of the volcano, that the lavas slope steeply from the elevated platform down to the base, so in Madeira, on the north side of the main axis, the lavas have a uniform steep inclination to the sea, there being on that side, as the numerous ravines show us, no lateral buried chain which could present any obstruction,—no intercolline space like that on the southern slope to cause the lavas to become horizontal*.

It follows as a corollary from the views above set forth, that in the cone-making process the force of upheaval from below, if it has acted at all, has only exerted a subordinate and possibly a very local influence, and the admission of a double axis for Etna draws with it the abandonment of the "elevation-crater" hypothesis; for however conceivable it may be that one cone of eruption should envelope and bury an adjoining cone of eruption, it is obviously impossible that one cone of upheaval should mantle round, overwhelm and bury another cone of upheaval.

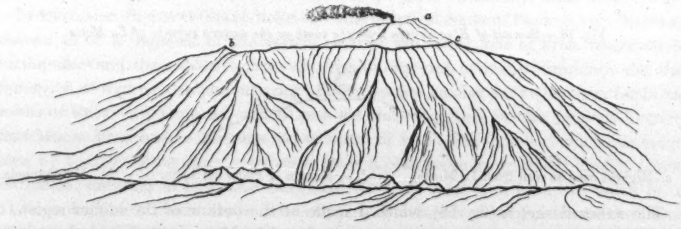
* See section of Madeira, 'Manual of Geology,' chap. xxix. fig. 653, p. 517, 5th edit., where A is the central axis, *e* R the intercolline space filled up, and *c f* the secondary chain buried under 2000 feet of lava and scoriæ.

Want of continuity in the older and modern parts of Mount Etna, and truncation of the summit.

The evidence on which some writers rely in proof of a discontinuity of the operations which produced the old nucleus of Etna, and those which formed the more modern portion of the mountain, seem to me far from conclusive; for on the north-west, the west, and part of the south-west sides, there may have been a regular and almost uninterrupted superposition of conformable volcanic products, from the oldest known trachytic to the most modern doleritic lavas*.

S. von Waltershausen has shown that the oldest series of dikes intersecting the lavas are dioritic, only one dike of trachyte having been seen by him. Next to the dioritic or greenstone dikes come those of a kind of slaty basalt, to which he gives the name of phonolite, while the third and last series consists of dolerites and greystones, or "trachi-dolerites." That in certain parts of the mountain particular sets of lavas should be found resting unconformably on other and older rocks was to be expected, as the necessary consequence of three great events which have successively worked a change in the physical geography of Etna; namely, first, the interference of the products of the two foci, or the overflowing of Trifoglietto by the newer part of Mongibello, as before described (fig. 15, p. 740); secondly, the truncation of the summit of Mongibello, to which I shall presently advert; and thirdly, an event in part perhaps contemporaneous

Fig. 17.—*Truncated appearance of the summit of Etna on the north-west side, as seen from near Bronte, from* Sartorius von Waltershausen's Atlas, plate 2.



a. Modern cone. *b, c.* Margin of convex area or highest platform.

with the last mentioned, the formation of the Val del Bove,—that wide and deep chasm into which so many floods of lava have since been poured, as if the eruptive powers

* The rock here called trachyte, is so designated by MM. S. v. Waltershausen and Abich, as it appears to me with propriety, although von Buch considered the name inappropriate, because the felspar he says is labradorite and not glassy felspar. The ordinary appearance of the felspar, whether in the older or newest lavas of Etna (including that of 1852), is like glassy felspar, so far as having the same vitreous lustre. The composition of the mineral in the trachytes above alluded to is said by S. v. Waltershausen to be intermediate between labradorite and oligoclase. Crystals of hornblende and of augite accompany it, but no quartz, —mica very rarely, and only as an accidental mineral.—S. v. Waltershausen's Atlas, V. and VI. p. 3.

were striving to repair the injury done to the symmetry of the cone, and restore to the volcano its proper and normal shape.

That the cone of Mongibello was once higher, and that, like a large number of active volcanos, its summit has been truncated, appears from the occurrence at the height of more than 9000 feet of a convex platform, which, according to S. v. WALTERSHAUSEN'S measurement, is 4150 metres in its longest, or S.E. and N.W., and 3000 metres in its shortest diameter.

[The annexed outline view (fig. 17) will show the manner in which the modern cone (*a*) rises from near the western margin of the platform (*b*, *c*), which S. VON WALTERSHAUSEN considers as the remnant of a crater named by him the "Cratere Elliptico" nearly filled up, but part of the outer wall of which still remains, and which will be described in the sequel. The area called the Piano del Lago, situated at a lower level to the south of the highest cone, is regarded by the same observer as marking the site of another distinct centre of eruption, or filled-up crater, 2600 metres in diameter; but I was unable to verify this opinion, there appearing to me no sections sufficient to establish the fact of a long-continued series of eruptions from any fixed point, other than the present culminating focus. There is, however, such a tendency in volcanos to shift their principal points of discharge, that a geologist cannot object to such an hypothesis, if it can be shown that we can thereby best explain any observed phenomena; and it was probably owing to the limited period of my visit, that I failed to obtain proofs of two adjoining craters formed by paroxysmal explosions and then afterwards filled up to the lips by lava and scoriæ.

Fig. 18.—*Summit of Etna as seen from the south or the eastern suburbs of La Motta.*

a. Highest cone as seen from La Motta. *b*, *c*. Margin of Piano del Lago. M. Montagnuola.

The annexed sketch (fig. 18), which I made of the outline of the higher region, as seen from the south or from the eastern suburbs of La Motta, will show in how analogous a manner the modern cone rises there above the Piano del Lago.

The geologist must not infer, from the term Piano, that there is really any extent of level ground or table-land near the summit of Etna. The whole area surrounding the cone might rather be compared to a flattened dome, from which rise several volcanic hills of considerable size, such as that of the Torre del Filosofo, and another much more lofty, called Monte Frumento, rising due south of the Casa Inglese. These have the ordinary external characters of lateral cones produced by single eruptions.]

[*Elliptical crater.*—I regret that I was unable to visit what is still extant of the walls of the "Cratere Elliptico" of S. VON WALTERSHAUSEN, which is situated north and north-

west of the great cone (see Map, Plate L.); but my friend, Signor GAETANO G. GEMMELLARO, has had the kindness to explore it at my request, and has communicated to me for publication an account of it, in a letter dated Catania, October 18, 1858, in which he replies fully to the numerous questions I had put to him. He found the eastern remnant of the old crater-wall (that lying east of the lava of 1809) almost concealed under recent volcanic sand and fine scoriæ, to such an extent that it was extremely difficult to determine even the site of the ruins which S. VON WALTERSHAUSEN discovered many years ago. But the other fragment which lies to the west of the recent lava of 1838, "is still," says Signor GEMMELLARO, "clearly exposed to view, forming for 1100 paces an arc of a circle round the present axis of Etna; its mean height 11 metres, or 36 English feet. It is composed of alternations of lavas and fragmentary materials, or scoriæ, sand, and lapilli, its upper margin broken and serrated. The lavas, except the bottom bed, which is nearly 6 feet thick, are thin but compact, the upper beds, however, becoming more cellular. All the lavas are inclined steeply to the north at an angle of 31°, the average of many measurements. Most of them are continuous from one end to the other of the elliptical crater, but some of them thin out in their extension from east to west. They are not strictly parallel, but present slight undulations. Several dikes occur, of which two especially are conspicuous. The principal one is 3 metres wide, of a reddish colour and schistose fracture, and decomposing rapidly. It does not reach the upper part of the precipice, but terminates about half-way up. The direction of both dikes is nearly north and south, or exactly towards the centre of the present axis of Etna. The smaller one has the same structure as the larger, but its thickness is much less."

In conclusion, Signor GAETANO believes "this elliptical crater of Baron S. VON WALTERSHAUSEN to be a fragment of the ancient cone of the actual axis of Etna, destroyed by earthquakes and the explosive force of gases during one or many eruptions; also that the epoch of that catastrophe may not be very remote, geologically speaking; for in the works of RECUPERO, FERRARA, and ALESSI, we find,—1st, that SENECA reminds LUCILIUS that Mount Etna had in his time lost so much of its height that it could be no longer seen by boatmen from certain points whence it was previously visible; 2ndly, UGONE FALCANDO, referring to FILOTES, relates that the lofty summit of Etna had fallen in, in 1179, in the time of WILLIAM the Eleventh; also that it was destroyed, for the third time, in the reign of FREDERICK the Eleventh, in the year 1329, as FAZZELLO relates. Moreover, that it was engulfed, for the fourth time, in the year 1444, according to the authority of the same writer, and of FILOTES and CARRERA; and finally, in the year 1669, nearly the whole top of the mountain fell in*."

If within the last 2000 years such revolutions have been witnessed in the upper region of Mongibello, it may well be supposed to have experienced a far greater transmutation by the reiterated catastrophes of the ten or twenty thousand years which immediately preceded the historical period, during which time there may have been, within the area of the highest platform, several summits blown off, and several deep craters formed and

* ALESSI, Storia critica dell' eruz. dell' Etna, p. 149.

filled, and possibly some centre of discharge, bearing to the actual crater the same kind of relation which the Chahorra now bears to the Peak of Teneriffe.

I found on the summit of the highest cone, when I visited it, September 21, 1858, two craters, one, the western, much smaller than the other, and separated by a narrow wall of highly inclined beds of ejected scoriæ from the chief abyss, implying that within this limited space the modern eruptions have not been strictly constant to one focus.

JUNGHUHN infers, from his experience in Java, that where there are two permanent foci of eruption in the same mountain, they are to be considered as a fragment of a chain of volcanos. If a third occurs, as sometimes happens in one and the same Javanese group, the three are always linearly arranged. In like manner, S. VON WALTERSHAUSEN imagines that in the upper part of Etna (or the area of the axis of Mongibello) the two ancient centres, before alluded to, are in a line running N. 36° 48′ W., which, if prolonged, would strike the axis of Trifoglietto. He therefore supposes all the eruptions of these three foci to have broken out along one great fundamental fissure*. I was unable, as before stated, p. 746, to find sections to test or bear out these generalizations.]

By reverting to the section (fig. 16, p. 743), the reader will see that the great northern escarpment of the Val del Bove, called the Concazze, terminates in its higher or western extremity in a precipice, which faces the present active cone or axis of Mongibello, and consists of lavas which dip steeply away from that axis. When this elevated portion of the Concazze was formed, the great crater of eruption may perhaps have been more to the north than now, and the cone was probably loftier than that which now exists. Be this as it may, we cannot account for the present shape of the northern and southern escarpments of the Val del Bove, and the manner in which they slope away from the highest cone, without assuming that before the Val del Bove originated there was but one conical mountain, which embraced within it the subordinate and buried cone of Trifoglietto. By this hypothesis alone can we explain the superior altitude of the western boundary of the great valley, and the gradual diminution in height of the two great escarpments as they trend eastward.

The reader will be better able to restore in imagination the former outline of the single cone, before it was truncated at the top, and before it was indented by the great valley on its eastern flank, by referring to plate 12 of S. v. WALTERSHAUSEN'S 'Atlas,' where an accurate and very descriptive view is given of the eastern slope of Etna, including the Val del Bove, as seen from the Torre d'Archirafi, a point south of Riposto, on the sea-coast.

Hypothesis of upheaval by injection.

I have stated, in my preliminary remarks, that geologists, who take for granted that lava cannot congeal in continuous stony layers on slopes exceeding five or six degrees, must unavoidably embrace the conclusion that nine-tenths of the strata which constitute the nucleus of Etna, and not a few of the beds which overlie that nucleus unconform-

* Atlas von Etna, part 7. p. 3.

ably, were brought into their present position by mechanical forces after the materials of the mountain had accumulated on nearly level ground.

It has been suggested by M. ELIE DE BEAUMONT, that when (as during the eruption of 1832) new fissures are produced, radiating from the centre, and traversing the nucleus of Etna, and when lava, after rising simultaneously to the rim of the highest crater, has filled such fissures, there may result an upheaval of the whole cone, and in this way the tumefaction or distension of the mass may have been going on. He even thinks that the cone may acquire as much height by this machinery as by the accession of new external coats of lava.

I may first be allowed to remark, that if such a doctrine be embraced, it would help us to dispense with that paroxysmal violence or grand terminal catastrophe which holds so prominent a place in the "crater-of-elevation" hypothesis.

[Unfortunately we have at present no data for deciding whether the dike-making process thus appealed to is usually attended by upheaval. That on some occasions it indicates a collapse and partial subsidence of the flank of the cone in such a manner as might either increase or diminish the angle of dip, seems proved by the observations of SCACCHI on Vesuvius in 1850 and 1855, and by those of JULIUS SCHMIDT in 1855. The last-mentioned observer looked in vain, in the walls of the long cavity caused by subsidence (and in which probably a new dike was forming by injection of lava into the flanks of the cone), for signs of upheaval*.

That an uplifting of the incumbent mass must accompany the injection of liquid matter through fissures which are not perpendicular, some of which, as I saw in the Serra Intermedia, are inclined at an angle of 75° to the horizon, no one can deny. Such injected rents, when very wide, must modify greatly the position of the overlying and intersected beds, both in a horizontal and vertical direction. S. VON WALTERSHAUSEN, therefore, while rejecting the hypothesis of a single terminal catastrophe, or any paroxysmal development of the elevating force, ascribes no small influence to those disturbing operations, by which such innumerable dikes have been formed near the principal centres of eruption.]

The same author, who has studied Etna for a longer time and more attentively than any other geologist, supposes the volcano to have assumed its present form and dimensions gradually by the joint effect of the overflowing of lava and the injection of the same, not only into vertical fissures, but in sheets parallel to the previously deposited tuffs and lavas. By these intercalated and conformably intruded masses, according to him, much elevation has been brought about, an hypothesis to the discussion of which I shall presently return. The great point to be chiefly kept in view in the present memoir, is simply whether the quâquâversal arrangement of the beds, in cones like Etna and Somma, and the high inclination of the lavas and scoriæ, are not mainly, and in many cases exclusively, due to eruption, and whether the upheaving power, even granting its intervention, does not play a very subordinate part. On this head we may con-

* Die Eruption des Vesuv im 1855, p. 44. (Wien, 1856.)

sider which of two propositions is the more likely to be true; first, the one advanced by M. Elie de Beaumont, that a large portion of the strata in the nucleus of Etna, as seen in the Val del Bove, and now dipping at an angle of 28°, had an original slope of only 5° or 6°, the remaining 20° or 22° being due to upheaval; or secondly, the converse of the above, namely, that 23° may have been the original average inclination, and that the additional 5° or 6° may have been gained by subsequent movements,—in other words, a fifth part alone of the whole dip, save in a few exceptional cases, may be ascribable to elevation.

In favour of the doctrine that the lavas and tuffs of Etna have been subjected to disturbing forces, two arguments have been advanced; first, it is said that the rocks of fusion, as well as those composed of fragmentary materials, are inclined in many places at angles steeper than those at which they could possibly settle on the slope of a volcanic cone; 2ndly, that in the Val del Bove alternate strata of rocks of both kinds preserve a uniform thickness and parallelism over exceedingly wide spaces, entire sets of them preserving their parallelism at points where they are all bent at once, and made to assume a new position with quite a different dip (see below, p. 753). I shall begin by considering the first of these arguments, the only one, according to my observations, to which any real weight can be attached.

The steepest dip of beds in the modern or highest cone of Etna amounts to 39°; the most considerable which I saw in Vesuvius was on the exterior of a small cone, then in the process of growth (October and November 1857), where the slope was 42°; but in that case, as before stated, p. 737, I believe the scoriæ, which were red-hot, and which formed a sheet of matter glowing like lava after it had fallen, to have been in such a state of semifusion as to be capable of becoming agglutinated or soldered together.

Every observer will grant that the dip of nine-tenths of the lavas, tuffs, and agglomerates seen in sections of the Val del Bove, fall short of the angles above alluded to, and that by far the larger part of them are under 30°. The steepest inclination which I measured was in the outlying rock in the Val del Bove, called Finocchio Inferiore, where the beds, consisting of red scoriæ, with a few intercalated layers of lava, dip at one point, at angles as high as from 45° to 47°, towards the N.W., whereas other beds near them, and separated only by a dike, dip from 30° to 38° N.E. The scoriæ here are of such a nature as might originally have had a very steep dip, and they are traversed by so many dikes, some vertical, others many degrees out of the perpendicular, that no geologist would deny that local fracture and subsequent dislocations may have operated as disturbing causes, to say nothing of the possibility of such an outlier having had its position altered bodily by that subsidence, and those explosions to which we refer, in part at least, the origin of the great valley.

[In the lofty escarpment of the Serra del Solfizio, near the Montagnuola, the beds of lava, scoriæ, and fragmentary matter (the latter greatly preponderating in volume over the lava) are horizontal, or nearly so, in the upper half of the precipice, while in the lowest, 800 or 1000 feet, they have a steep inward dip away from the Val del Bove.

This arrangement of the beds, first observed by Baron S. von Waltershausen, I verified, as before stated (p. 741), in 1858, in the projecting promontories of rock called Cuvigghiuni, Serra Intermedia, and Vavalaci (see Map). In one of these (Cuvigghiuni) S. von Waltershausen counted no less than forty dikes of various ages, which have invaded the inclined strata, the oldest dikes, composed of greenstone, being often of great width, and being crossed and shifted by the more modern or doleritic ones, and many of both kinds being out of the perpendicular.

Here and in the adjoining Serra Intermedia, there are points where the volume of the intrusive matter seems equal to the rocks which they penetrate, and we cannot therefore be surprised if, under such circumstances, we should see, in the lower half of the escarpment, dips exceeding 40°, an inclination which we cannot ascribe to the original position of the beds. But after measuring the dip at numerous points, even here, where the dikes most abound, I found it rarely above 33°, while occasionally it only amounted to 15°. Amidst all these variations I saw no case of a reversed dip, or a dip towards the Val del Bove.]

The beds in the lower half of the Serra del Solfizio were probably from the first very steeply inclined, for they consist chiefly of agglomerates, containing many angular fragments of lava, implying a neighbouring vent; and we need not perhaps attribute more than a fifth part of their present dip to a tilting of the mass by subsequent disturbances.

The fact that the steepest dips occur where the dikes are most numerous, may be thought by many to favour the doctrine that the high inclination of the beds was the effect of the injection of melted matter into such innumerable fissures. Without denying that it may sometimes have been an auxiliary cause, we must, on the other hand, remember that the dikes are always nearest the great centres of eruption, and that there are three reasons why the original dips should be greatest near such centres:—1st, because the heavier and larger fragments of rock thrown out of the crater fall nearest to its margin; 2ndly, because the red-hot scoriæ, as before mentioned, are sometimes agglutinated together; and 3rdly (an influential circumstance too often overlooked), because streams of lava frequently stop short when they have crept but a small way down the declivity of the cone. [The effect in steepening its flanks of this midway halting of many lavas, was strikingly exemplified high up on the north slope of Vesuvius, between the years 1855 and the close of 1857, especially in July of the year last mentioned. The inclinations of the recent lavas observed by Signor Guiscardi and me, amounted to 30° and 35°, and even for short distances, 39° and 42°.]

[*Supposed frequent injection of lava in beds conformable to tufaceous strata, considered.*

It has been already hinted (p. 749) that S. von Waltershausen attributes much of the upheaval of the mass of Etna to the intrusion of conformable lavas between previously deposited layers of tuff and fragmentary matter. He ascribes, for example, such an

origin to most of those lavas of Sciuricosino near Zafarana, which are bent into arches, and which thin out in both directions, as represented by him in plate 20 of his 'Atlas.' Yet these occur far from the region where dikes are frequent, and where we have positive proof of the injection of melted matter into rents. That near the great centres of eruption, where the hade of the many dikes is so much out of the perpendicular, and where some are tortuous, and are seen to cross and shift others, there should be found occasionally sheets of intrusive matter parallel to the tuffs and older lavas, will be readily conceded. Mr. HARTUNG and I observed in Madeira, at the western extremity of Cape Giram, some dikes which were nearly horizontal, and had been injected, for a certain portion of their course, between sheets of pre-existing lava; but these dikes, like some of similar origin above Guimar in the Island of Teneriffe, were ascertained by us, when we traced them for 30 or 40 feet, to cut through the regular lavas and tuffs; and in the case of Cape Giram in Madeira, they give rise to faults in the older beds, a rare phenomenon in Madeira, as it is also on Mount Etna.

Had the lavas which slope away from the ancient centres of Trifoglietto and Mongibello been in great part injected between the tuffs, we should have frequently seen them penetrating through the dikes. But though these last are of so many different ages, and are continually seen to traverse the alternating lavas and tuffs, I could discover no instance of such dikes being in their turn traversed by the lavas. It may be asked how, in the escarpments of the Val del Bove, we can distinguish a lava, which has flowed originally at the surface, from a tabular mass of rock, which may have been forced, when in a melted state, into a fissure betwen two layers of tuff? I reply, that the lava has almost invariably its upper and lower scoriæ, and sometimes immediately beneath the latter a red layer of burnt tuff, such as I saw in the Balzo di Trifoglietto, at various heights, and in Monte Zoccolaro and in the valley of S. Giacomo, where I traced a red tuff for a great distance underlying the most powerful of the older lavas. Such red layers are never in direct contact with the central and overlying crystalline stony layer, for there intervenes always a fundamental stratum of fragmentary or scoriaceous matter between the stony bed and the burnt tuff below. On the other hand, I looked in vain for an instance of some powerful sheet of lava which had one of these brick-red clays *above* as well as below it. Had the crystalline lavas, whether trachytic or doleritic, whether slightly or steeply inclined, been in great part intrusive, they would have altered the tuffs as much above as below them. Moreover, they must have given rise to innumerable faults; for while they vary in thickness from 3 to 60 feet, they are not, as I shall show in the sequel, persistent for indefinite distances, but often thin out rapidly in both directions. They ought, therefore, had they been injected, to have lifted up the incumbent deposits partially, so as to give rise to many conspicuous faults. For these reasons, I cannot adopt the conclusion that the upheaval of Etna has been largely due to the injection of lavas in sheets parallel or conformable to the tuffs and fragmentary materials.]

Evidence of pseudo-parallelism and want of uniform thickness of the beds forming the escarpments of the Val del Bove.

M. Elie de Beaumont, in his celebrated Essay on Mount Etna before cited, has represented the escarpments of the Val del Bove as being composed of many hundreds of perfectly regular beds, formed alternately of rocks of fusion and of fragmentary and pulverulent materials. He describes the thickness of the beds as varying from a few inches to several yards, but averaging about 6 feet each, the fragmentary beds being generally, though not always, thicker than the lavas. At the same time, he insists on the remarkable uniformity in thickness and parallelism of the several members of this whole series, and their continuity for great distances, a fact adduced as confirmatory of the doctrine that the beds were originally horizontal, and were afterwards brought by upheaval into their present position. The same author states, that "the most general and the most conclusive character of the numerous beds of fused and fragmentary matter consists in this, that they are liable, all of them, to be bent together as they pass in several different directions, from a nearly horizontal position to an inclination of from 25° to 30°, without either their structure or their thickness being altered with any degree of regularity*." The volcanic strata are therefore likened by him to the regular sedimentary formations which have undergone great flexures in mountain chains.

To begin with the northern escarpment of the Val del Bove, we obtained (Signor G. G. Gemmellaro and I) a good general view of the precipices composing it, from Monte Finocchio Inferiore and its neighbourhood. First we turned our attention to part of the nearly vertical cliff immediately N.E. of our station, where the height exceeds 1000 feet. It was called by our guide the Serra di Cerrita, and is part of the Concazze. We could count in this part as many as sixty beds, more solid and prominent than the rest, which we had no doubt were lavas or rocks of fusion, and we recognized in the series many marked deviations from parallelism. One case in particular was very conspicuous, for a single bed of rock (*a*, fig. 19), the thickness of which we estimated roughly at 40 feet, was represented or replaced, at the distance of a few hundred yards westwards, at *b*, by

Fig. 19.—*Want of uniformity in thickness in stony layers in northern escarpment of Val del Bove.*

Thickest part of *a* 40 feet.

* "Le caractère le plus général et le plus concluant de ces nombreuses assises de matières fondues et de matières fragmentaires qui alternent pour former le noyau de la gibbosité centrale de l'Etna m'a paru consister en ce qu'*elles sont sujettes à s'infléchir toutes ensemble, en passant dans plusieurs directions diverses, d'une position à peu près horizontale à une inclinaison de 25° à 30°, sans que leur structure ni leur épaisseur en soient altérées d'une manière constante.*" The italics are in the original. Mém. pour servir, &c., pp. 130, 131. Again, we find, p. 165, "l'uniformité d'épaisseur et l'exacte parallelisme que conservent au milieu d'inflexions variées," &c.

two hard beds, with several intervening layers of a different and less solid composition. In another part of the same escarpment, and not far distant in the upper half of the cliff, the harder beds presented the irregularities sketched in the annexed woodcut (fig. 20), the

Fig. 20.—*Non-parallel strata in the northern escarpment of the Val del Bove, to the south of Finocchio Inferiore.*

Vertical distance from *a* to *b* about 60 feet.

aggregate thickness of the mass, including the softer intervening beds, being about 60 feet. Between perfect parallelism and such marked deviations from it, as are here indicated, there is every intermediate gradation.

[In the higher and more western portion of the same escarpment, called the Concazze (or by ABICH the Cima della Valle), where the stratification has been described as very regular and parallel, I distinctly saw a similar thickening and thinning out of the beds as viewed from the rim of the great crater of 1819, the want of parallelism being most conspicuous in the upper parts of the precipice.]

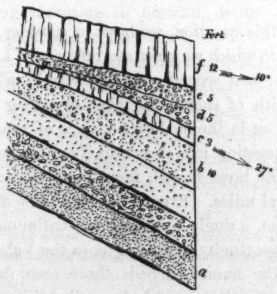
To speak next of the southern escarpment. I may first remark, that when a cliff is between 1000 and 2000 feet in height, like the Serra del Solfizio, we can only obtain a general view of its hundreds of strata by placing ourselves at a considerable distance from its base; in which case all the minor variations in dip and in the thickness of individual beds may escape notice, unless specially looked for.

M. ABICH has given an excellent pictorial representation of this cliff in his eighth plate, taken from the foot of Zoccolaro, and has called attention to the general uniformity and regularity of the lines separating the numerous beds. But even in the Serra del Solfizio, at certain points where the steep cliffs were accessible, and where we measured the angles of dip and the thickness of the beds, we invariably found the appearance of strict parallelism and uniformity of stratification to vanish. Before adducing particular examples, I may observe that, besides the height and magnitude of the section, the number of dikes, mostly perpendicular, but some of them having a considerable hade, and still more the numerous ravines which have been excavated by torrents, causing gaps from 150 to 300 feet in width, add prodigiously to the difficulty of tracing a particular bed for an indefinite horizontal distance. The gaps alluded to cause the intervening promontories of rock to jut out like the side-scenes in a theatre when seen in profile, as is well represented in ABICH'S sketch above cited.

At the first point where we tried to ascertain whether the strata were persistent throughout wide spaces, we found such a want of correspondence on the opposite sides of one of these ravines, that we began to suspect that we had at length discovered a great

fault shifting the beds vertically for several yards; but we soon satisfied ourselves that a gradual change in the thickness of particular beds afforded the true explanation. The ravine alluded to is in the Serra del Solfizio, about midway between the Rocca del Corvo and the hill of Zoccolaro (see Map, Plate I.). It is about 300 feet wide, and runs north and south. The strata consist chiefly of agglomerates, some containing much scoriæ and large angular pieces of lava. We may expect such beds to be more continuous and uniform in thickness throughout wide spaces on the flanks of a volcano than single currents of lava, because during violent eruptions the ejectamenta are scattered by the explosive action of gases and by the winds over extremely large areas. The first mass, about 80 feet thick, which we examined near the base of the cliff, on the west side of the ravine, was divided into beds which varied in their dip from 24° to 28°, when viewed in a north and south direction; while in the east and west section, or that which faces the Val del Bove, we found a want of parallelism in the same beds amounting to 15° in the space of a few hundred yards. In the above-mentioned 80 feet there were only six layers of lava, the united thickness of which was no more than 10 feet. We next observed another vertical mass, on the east side of the same ravine, where the agglomerates were in like manner very preponderant throughout a thickness of 300 feet, the dips varying from 28° to 18°, and diminishing as we ascended. Immediately above we came to another section, represented in the annexed diagram (fig. 21). At the bottom are

Fig. 21.—*Want of parallelism in the beds in the Serra del Solfizio, south side of the Val del Bove.*

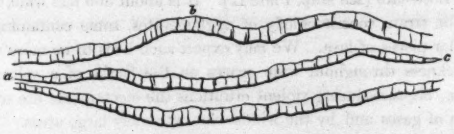


several beds of agglomerate (*a* to *b*); then a doleritic lava (*c*), about 3 feet in its greatest thickness, and inclined at 27° S.; over that again a bed of scoriæ and agglomerate (*d*), 5 feet thick, which at the distance of a few yards thinned out entirely at *g*; above this is another bed of scoriæ and agglomerate (*e*), 5 feet thick; and over that a lava (*f*), 12 feet thick, inclined at 10°; so that here, in a vertical height of little more than 10 feet, the want of parallelism of the two lavas *c* and *f* amounted to 17°.

At the eastern extremity of the Serra del Solfizio in the hill of Zoccolaro, we observed,

among other irregularities, three beds of lava (see fig. 22), varying from 4 to 6 feet in thickness, and separated by strata of incoherent matter. When followed for a distance

Fig. 22.—*Curvatures in the lavas of Zoccolaro.*



of between 200 and 250 feet, the middle bed thinned out at *c*, while the upper and lower lavas, instead of being about 40 feet apart, as below *b*, bend in such a manner as to come within 12 or 14 feet of each other, as at *c* and *a*.

Upon the whole, the term pseudo-parallelism, which Mr. HARTUNG and I were in the habit of applying to the volcanic beds of Madeira and the Canaries, seems to me equally applicable to the Etnean formations, when these are analysed in detail.

Analogous form and arrangement of ancient and modern lavas.

It may still be asked, are there not single continuous beds of lava, intersected in the escarpments of the great valley, of wider extension than we can possibly explain on the hypothesis of their having flowed down the flanks of a volcanic cone in the manner of ordinary lavas?

Before we can reply to this question, we have to consider two points; namely, first, whether the ancient rocks to which we refer are intersected longitudinally, or in a direction transverse to their dip; and secondly, if transversely, what accurate data have we respecting the average width of such beds, whether among the older lavas of Etna, as seen in the Val del Bove; or in the modern products of Etna, Vesuvius, or any known volcano? As to the first question, it is clear that if our sections are longitudinal, that is, in the direction in which the lavas flowed, there is no reason why a stony layer should not be continuous for several miles. Even if the section be diagonal in reference to the original course of the stream, a single layer may be continuous for as great a distance as we are likely to have an opportunity of tracing it in the Val del Bove. The prevailing dip towards the east of the numerous beds there seen, both in the northern and southern escarpments, accompanied as it is by a diminishing height of the mountain as it stretches eastward, implies, according to the theory of eruption, that the currents of melted matter flowed eastward, and are therefore cut open longitudinally or more or less diagonally; whereas the lavas, if any, which came down from the axis of Mongibello after the overwhelming of the cone of Trifoglietto, would naturally take the same, or nearly the same direction.

α[In regard to the second question, if we admit that some of the lavas and agglomerates which depend on the axis of Trifoglietto are really intersected in a direction at

right angles to their dip, both in the Serra Giannicola and Serra del Solfizio, we soon discover that we are wholly in want of data to test the point at issue. We have no means of ascertaining whether any single stratum is persistent for an indefinite distance in a direction at right angles to the original course of the lava. The sections afforded by the Serra Giannicola and by the rocks under the Montagnuola (Cuvigghiuni, Serra Intermedia and Vavalaci), are all too interrupted to allow us to follow any single bed of rock very far in its line of strike. Even in the Serra del Solfizio the gaps before alluded to impede observation, and we have said enough to show that the alleged continuity and parallelism of the beds in that range of cliff is a delusion. If, on the other hand, we seek information as to the average breadth, depth, and dip of lavas on the slopes of any modern cone, whether near the lip of the crater or half-way down, or near the base of the mountain, we find ourselves still more in the dark. In order to appreciate the truth of this remark, we have only to consult the excellent monograph of Vesuvius recently published by Dr. ROTH of Berlin, in which he has given us a judicious and elaborate analysis of the multitudinous memoirs and treatises on the eruptions of that volcano since the year 79. In consequence partly of the want of sections on the flank of a growing cone, and partly of inattention to facts supposed to be of no theoretical interest, we fail, in spite of the high scientific attainments of so many of the observers, to obtain in any one instance the three data of which we stand in need. Some record the thickness, others the width, others the dip of a given lava-current, or the slope down which it flowed; some few mention two of these conditions, but no one all three; still less do they record facts respecting variations in breadth, depth, and inclination at various points between the summit and base of the cone*.

In S. v. WALTERSHAUSEN'S great map of Etna, we perceive that certain currents, radiating in various directions from the highest crater and platform (see Map, Plates XLIX. and L.), have the appearance of narrow stripes, yet prove, when measured at right angles to their course, to have a width of from 300 to 1800 feet. We cannot ascertain their average depth, but, judging by their external form, they probably exceed in thickness most of the old lavas intersected in the Val del Bove. Nevertheless they

* [Since writing the above, I have found some valuable observations on this subject, published by Mr. JULIUS SCHMIDT of Olmutz, on the lavas of 1855, 'Eruption des Vesuv. im Mai 1855,' p. 56. I have also myself revisited (September 1858) Vesuvius and the Atrio del Cavallo, in company with Signor GUISCARDI of Naples. We measured the depth and width of several lavas of 1857, resting on slopes of 18°, 24°, and 28°, and we compared the results with those supplied by the older lavas in the escarpments of Somma, in order to see if any of the latter were of greater width when intersected transversely to their dip. After surveying many hundreds of layers, we found only one, near the entrance of the Atrio, on the side of the Observatory, decidedly more persistent than the modern lavas examined by us. There are beds having the appearance of hard stony layers which are conspicuous in the walls of the Atrio, and which might easily be mistaken for lavas, but which consist of solid tuffs. The exception which we saw might, we thought, be accounted for by some accidental irregularity in the external slope of the old cone, producing a gibbosity such as has been formed in the last few years on the northern side of the modern Vesuvius, and which, by interrupting the free course of a descending current, might cause it to spread out laterally.]

may be subdivided into several sheets, lying one over the other, just as the lava of 1669 is seen in Catania, in the shaft artificially cut through it near the sea in the Villa Filippino, to be about 80 feet thick, but separated into ten beds, most of them with scoriaceous partings, caused by a succession of flows during the same eruption. This same lava in the northern suburbs attains a thickness of 60 feet in one magnificent crystalline mass, without any such bedding. I allude to the quarries at the Botte dell'Acqua, where the compact stone has a light grey base not unlike some trachytes, through which are scattered well-formed crystals of felspar and augite with some olivine. Let us now assume the narrowest of the recent lavas above mentioned near the summit of Etna to be 300 feet broad, and suppose one of the subordinate layers to be 8 feet thick, the analogy of all the sections above described leaves scarcely any doubt that it would consist of an upper scoriaceous crust, say 3 feet thick, a middle stony layer of about the same thickness, and a bottom scoriaceous stratum of 2 feet. The dip just below the edge of the platform is 24°, and we should then have a highly inclined tabular sheet of stony lava, which, in reference to its vertical and horizontal dimensions, would be in the proportion of 1 to 100, forming therefore a thin stratum. We have already considered (at p. 735, fig. 13) what would be the appearance of several such juxtaposed currents, if seen in a transverse section; but it should be borne in mind that we cannot look for a strict analogy in the breadth, average thickness, and degree of compactness in lavas of ancient and modern cones, unless we are able to compare sections of such cones at corresponding heights, which is usually impossible.

Flexures and arches in ancient lavas.

In order to guard against imagining a contrast between older and newer lavas, where none really exists, we must remember that the steeper the angle at which a current has cooled, the more parallel in general will be the planes of stratification of the several scoriaceous and stony layers which compose it. No doubt a great diversity of character prevails in this respect in lavas which have congealed on corresponding declivities, but I never met with ridges and furrows of great dimensions where the original slope exceeded an angle of 20°; and the rare occurrence of flexures on a gigantic scale in the steeply inclined lavas of the Val del Bove, has always appeared to me a fact in favour of the original steep dip of those lavas. We have already seen (p. 718, fig. 6, and p. 726, fig. 9, and p. 730) that the surfaces of the lavas of 1689 and 1852 are comparatively even and uniform where they have cooled on slopes of 30°, 35°, and 40°; whereas at points immediately contiguous, where the same currents have overflowed less inclined planes of 10° or 15°, they have been bent into gigantic folds and ridges. There may be exceptions to this rule, for some sharp and conspicuous flexures are visible in the escarpments of the Val del Bove, as for example, near the base of Monte Zoccolaro, in which there are two arches, one 15 and the other 20 feet high. So also in the northern escarpment above Rocca Capra (see Map II.), at about two-thirds of the height of the entire cliff above its base, a cave occurs 60 or 70 feet high, caused by the arching of

the lava and the washing out of the lower scoriæ. But these and other caves are exceptional, and the circumstances under which they occur deserve particular investigation, as they may perhaps be due to some local peculiarity in the external form of the ancient cone at such points.]

Dikes in the Val del Bove.

Dr. Carlo Gemmellaro, in several of his memoirs on Mount Etna published in the years 1835, 1847, and 1854*, &c., has argued against the "Elevation-crater" hypothesis, by calling attention to the steepness of the slopes down which some of the modern lavas of Etna have flowed; and he has particularly insisted on a fact, first pointed out by his brother Mario Gemmellaro, that a great number of dikes radiate from the present centre of Mongibello. Baron S. von Waltershausen, during his patient explorations of Etna, has also observed (see above, p. 741), that many dikes, thirteen or more in number, composed of greenstone, converge in like manner towards an ancient centre, called by us the axis of Trifoglietto. Assuming that all these dikes have been originally vertical, or nearly so, they might retain their verticality even after upheaval, if they radiated in exactly the same directions as the movements which uplifted the strata so as to make them dip away quâquâversally from a central axis. But in that case we should be under the necessity of concluding that the upheaval of the principal centre, namely that of Mongibello, has not interfered with or disturbed the position of the beds dependent on the lesser and adjoining cone of Trifoglietto, a conclusion quite inconceivable. All observers agree that there are a multitude of dikes which do not radiate from either of the two principal centres above alluded to, and it is impossible to reconcile the prevailing perpendicularity of the dikes with the steep inclination of the lavas and fragmentary strata which these same dikes intersect, unless we abandon the upheaval theory. For if a set of horizontal strata traversed by vertical dikes, radiating from more than one centre, and by other dikes not converging to any single point, were uplifted so as to dip at angles of 20° and 30°, it is obvious that the dikes also must become as much inclined relatively to the horizon as are the strata, the only difference being that the dip of the dikes and of the strata would be in opposite directions†.

Of the first three dikes which I measured in the hill of Calanna, I found two which were vertical, the direction of one being south-west and of the other 30° east, while the third, which had also a south-east direction (on the side nearest to Zoccolaro), was no less than 30° out of the perpendicular, its dip or hade being 60° south-west. In the Serra del Solfizio and elsewhere I saw many dikes which were vertical, where the beds intersected by them were highly inclined, while other dikes which were out of the perpendicular, were not inclined in the direction which the upheaval theory would require, but often precisely the reverse, their hade being towards the same point of the compass as the

* Sulla Costituzione fisica dell' Etna, 1847; and others in the 'Atti della Acad. Gioenia.'

† See my statement of this argument, with a diagram, in the 6th vol. of the Geol. Quart. Journal, p. 231, 1850; and Principles of Geology, 9th edit. p. 418.

dip of the beds. In volcanos in general the frequent association of highly inclined lavas and of numerous dikes, does not imply that the injection of melted matter into fissures has tilted the beds, but that near the principal crater, where earthquakes rend the mountain and where lava is ever ready to flow into rents, there are causes at work, as already stated at p. 751, to produce a steep slope in the ejected and outpoured matter.

When we recede four or five miles from the great centres of eruption on Mount Etna, still continuing within the domain of the old lavas, as in the valleys of Calanna, S. Giacomo, and Cava Secca, we find very few dikes, only three in S. Giacomo, and one in Cava Secca, which last is more remote from the centre of eruption; at the same time the lavas begin to dip less steeply, and to form a much more considerable proportion of the whole mass. The lavas, indeed, in these sections are sometimes separated only by such scoriæ as may have formed the top crust of an older and the base of a newer current, or occasionally by tuffs chiefly of alluvial origin.

Lateral cones of Etna.

I was surprised at finding no clear indications of buried lateral cones in the walls of the Val del Bove, since there are so many in Madeira at great depths, some of them overwhelmed by an accumulation of lavas and tuffs more than 1000 feet in thickness. Whether some of the irregularities of stratification and dip seen in the great escarpments and in outliers, such as Finocchio Inferiore, accompanied by many dikes, may be connected with ancient points of local eruption, is a fit subject for future investigation. The evidence, so far as I was able to inquire, did not seem to me satisfactory, and I therefore infer that, at the period when the two permanent centres of eruption were active (those of Trifoglietto and Mongibello), whether contemporaneously or in succession, there were few if any lateral outbreaks. The great phase of lateral eruption seems to have begun about the time when the truncation of Mongibello and the gradual formation of the Val del Bove were in progress, and after much bodily upheaval of Etna and the adjoining country had been gradually brought about.

Baron S. von Waltershausen has remarked* that there are certain spaces within the volcanic region of Etna, where lateral cones are wanting, or nearly so, and others where they abound. Thus he observes that in the direction from Paternò to Bronte, from S.S.E. to N.N.W., and again from Aci Reale towards Linguagrossa, from N. to S. (see Map, Plate XLIX.), there are two zones, each of them about eight miles broad, *without* cones; and again, there are two zones nearly parallel to each other, running from S.E. to N.W., where lateral cones are in great profusion, the first from Monte Trigona to Monte Egitto, and the second from M. Cubania to M. Spagnuolo; and these directions he thinks have some relation to the larger axis of the central nucleus of Etna, and to the strike of a certain set of dikes which do not radiate from the centres, whether of Trifoglietto or Mongibello, before mentioned. A glance at the Map which accompanies this paper, reduced by permission from S. von Waltershausen's large 'Atlas,' will show that

* Atlas, V. and VI. p. 4.

a very considerable number of cones do, as he observes, run in the zone first alluded to, namely, from Monte Trigona to Monte Egitto; but the other parallel zone from Cubania to Spagnuolo is so short and comparatively unimportant, that we might draw another exactly at right angles to it (*e. g.* from Monte Peluso, S.E. of Bronte to Monte Santo, near Linguagrossa), which would comprehend a zone of twice the length, and embracing at least double the number of points of lateral eruption. On the other hand, if we take the summit of Etna or axis of Mongibello as a centre, and draw a circle round it having a radius of ten geographical miles, we find that nearly all the lateral cones, 200 or more in number, all carefully laid down by VON WALTERSHAUSEN, are embraced within this circular area, with the exception of a few south and south-east of Nicolosi, and one or two others in the north, such as Monte Santo and Mojo; so that when we speculate on the causes of the present distribution of lateral cones, we find more connexion between them and the position of the great central focus, than with any supposed linear clefts running N.W. and S.E.

If, again, we contemplate the Map in reference to the spread of the lavas and make a circle round the same great axis, with a radius of about twelve geographical miles, we embrace nearly all the currents which ever flowed from Etna, whether of modern or medieval, or older date, except those near Catania of 1669 and 1381.

This last fact may help to bear out the conclusion stated at page 742, that the present axis of Mongibello may be as old or older than that of Trifoglietto, and may have always been the chief focus of eruption.

Recapitulation of PART II.

The following are the principal conclusions which I have endeavoured to establish in the second part of this memoir.

1st. The dip of the ancient beds of crystalline and fragmentary matter seen in the precipices surrounding the Val del Bove, are not such as to support the theory of a linear axis, nor of a single centre of upheaval for Mount Etna.

2ndly. The quâquâversal dip of the beds first observed by S. VON WALTERSHAUSEN away from an ancient centre, situated three miles to the east of the present summit of Etna, together with the horizontal or discordant dips of other superimposed lavas in the precipices at the head of the Val del Bove, imply the former existence of at least two permanent centres of eruption, and the final predominance of that which is still in activity, and which has overwhelmed the smaller or more eastern cone.

3rdly. The convergence of a large number of dikes towards the two supposed permanent centres of eruption is a fact corroborative of the theory above alluded to.

4thly. If such be the structure of Etna, and such the conclusions legitimately deducible from it, we must abandon the elevation-crater hypothesis; for although one cone of eruption may envelope and bury another cone of eruption, it is impossible for a cone of upheaval to mantle round and overwhelm another cone of upheaval so as to reduce the whole mass to one conical mountain.

5thly. The discontinuous and unconformable arrangement of certain parts of the ancient and modern products of Etna may be explained by supposing the former existence of two cones as above stated, and by the truncation of the ancient summit of the mountain, together with the contemporaneous or subsequent formation of the Val del Bove.

6thly. Although the cone-making process has mainly consisted of ordinary eruptions, yet the present steep dip of some of the old lavas and beds of scoriæ has been modified, especially near the ancient foci of eruption, by subsequent movements accompanying the rending and injection of the rocks, one-fifth perhaps of the present inclination of the beds being due to this cause, instead of four-fifths, as required by the elevation-crater hypothesis.

7thly. The alleged parallelism and uniform thickness of the beds in the escarpments of the Val del Bove, proves on closer inspection to be a delusion, for the lavas vary in strength and frequently thin out, being only persistent for great distances in the line of their dip, or the direction in which they originally flowed.

8thly. The ancient and highly inclined lavas are usually free from arches and flexures on a great scale, bearing a nearer resemblance to those parts of recent currents which have congealed on steep slopes than to those which have cooled on more level ground.

9thly. The scarcity of faults in the lavas of various ages, and the fact that the lavas do not cut through the dikes although the dikes so often cut through them, is opposed to the doctrine that a considerable amount of upheaval has been due to the injection of lavas in conformable sheets between pre-existing beds of tuff and scoriæ.

10thly. As the dikes are of various ages and do not all radiate from the two supposed centres of eruption, the verticality of so many of them is inconsistent with the elevation-crater hypothesis; for if the beds were originally horizontal, and owed their present steep dip to a final catastrophe, nearly all the dikes would be as much out of the perpendicular as are the intersected lavas and scoriæ.

Lastly. The absence of buried lateral cones in the escarpments of the Val del Bove, implies that the earlier eruptions were more concentrated and more limited to certain permanent vents than the modern ones.]

PART III.

ON THE RELATION OF THE VOLCANIC ROCKS OF MOUNT ETNA TO THE ASSOCIATED ALLUVIAL AND MODERN TERTIARY DEPOSITS, WITH CONCLUDING REMARKS ON CRATERS OF ELEVATION.

Origin of the Val del Bove, and how far due to aqueous erosion.

The origin of that large crateriform valley, or Caldera, called the Val del Bove, so often alluded to in the foregoing pages, has been sometimes attributed to a great and sudden catastrophe connected with those movements which are supposed to have given rise to the mountain itself, and to have caused simultaneously the steep outward dip of

the beds sloping away on all sides from a central axis. But if the section, fig. 15, p. 740, represent with any approach to correctness the internal structure of Etna, and if the reasoning advanced in the foregoing pages be sound, the reader will have come to the conclusion, that the whole mountain, with its lavas and tuffs sloping away from more than one centre, and pierced by a succession of dikes, was already complete before the Val del Bove began to be formed.

In the first edition of my 'Principles of Geology,' published in 1830–33, I considered how far this great valley might be due to three causes,—1st, engulfment; 2ndly, explosion; and 3rdly, aqueous denudation; and I concluded that it was probably due for the most part to engulfment. At a later period (1849*) I suggested that the sea might perhaps have once entered the valley and exerted a denuding power, an opinion which I did not maintain in later editions of my two treatises on geology, and which I entirely abandoned after visiting Madeira and the Canary Islands in 1854, when I became aware of the prodigious excavating and removing power which torrents and rivers can exert on a volcanic mountain, when once eruptions have ceased. Mr. DANA had already called attention to this fact in reference to certain volcanos in the Sandwich Islands†; and M. ZIEGLER, the eminent Swiss geographer, after surveying Madeira and publishing a Map of the island, remarked in 1856 to Mr. HARTUNG and me, that inclinations such as characterize the river-channels of that island would be excessive and quite exceptional in the Alps.

It may, indeed, be said to hold true generally in regard to volcanic as contrasted with non-volcanic mountains, that whereas in the latter the valley-making power is at work during the whole period of their growth, that same agency only comes into play in subaërial volcanos after their completion. The volume of rain-water and melted snow absorbed annually by a lofty mountain like Etna is so enormous, that if at length the underground drainage is converted into a superficial one, the force of running water operates with what we may regard as a compensating intensity, as if the waters had the power of making up for lost time.

Alluvium of Giarre.—In the first part of this memoir it was stated, p. 709, that an alluvial formation on which Giarre and other towns are built, and which sometimes rises to the height of about 400 feet above the level of the sea, attests the removal at some unknown period in the history of Etna, of a vast quantity of stony fragments from that part of the mountain which lies immediately to the westward, that is to say, in the direction of the Val del Bove. If it could be shown that all this transported matter came down from the great valley itself, it would go far to prove that the abstraction of the missing rocks was for the most part effected by aqueous agency. To enable the reader to judge how far such a conclusion would be legitimate, we must compare the alluvial formations of the eastern and other sides of Etna, for by such a comparison it will appear that those at the eastern base of the mountain, and especially those opposite

* Quarterly Geological Journal, "On Craters of Denudation," &c., vol. vi. p. 207.

† Geology of the United States Exploring Expedition, 1842.

the Val del Bove, are conspicuous beyond the rest by their volume, and by being exclusively composed of the wreck of the volcano itself.

The coarsely stratified mass before alluded to (p. 709) as forming the terrace on which Giarre stands, would be called "diluvium" by some geologists, and much resembles the "glacial drift" of Northern Europe and America; yet with this important difference, that none of the blocks, whether rounded or angular, have as yet been observed to exhibit polished surfaces with rectilinear striæ or scratches such as might indicate a glacial origin. The largest angular fragments near Giarre are occasionally 9 feet in diameter. The blocks are of trachyte, basalt, dolerite, trachi-dolerite or grey stone, and agglomerate; in short, of every variety of rock met with in the Val del Bove,—some evidently derived from dikes.

A great torrent, dry for a large part of the year, which passes by Giarre, has cut a wide channel through this drift, to the depth of more than 40 feet, without reaching the bottom; and near Mangano, about four miles to the south, there is a section of a similar alluvium, 60 feet deep, with rounded and angular blocks, some of large size, occurring at a higher level, and overlying the Giarre deposit, making the thickness at that place in all probability more than 150 feet.

The alluvial region (*a*, *a'*, Plate XLIX.), to which the above-mentioned drift belongs, extends ten miles from north to south, and about three from east to west. It has been correctly laid down by S. von Waltershausen in his Map, of which Plate XLIX. is a reduced copy. The lavas flowing from the Val del Bove have covered and concealed from our view a portion of its western limits, as we may infer from sections seen between Santa Venerina and Santa Leonardello, in the banks of a torrent which flows down from Zafarana. But the northern half of the area alluded to (*a'* Map, Plate XLIX.), which reaches from Giarre to the Fiume Freddo, has not borrowed its materials from the Val del Bove, but must have derived them from parts of the mountain immediately north of the northern escarpment of the great Caldera. In that tract, however, the thickness of the drift, as well as the average size of the blocks, is visibly less than in *a*, for the transported fragments, as before stated, are most voluminous where they ought to be so on the supposition that the Val del Bove was their source.

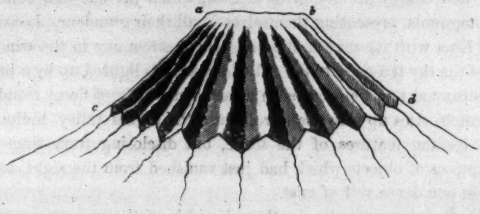
[*Valle del Tripodo, and proofs of aqueous erosion anterior to the Val del Bove.*

It may perhaps be suggested that the deposit of Giarre and Mangano might have been swept down by rivers from the old cone when it was still entire and before the Caldera originated, in favour of which theory it might be urged that in the Val del Bove at present we discover no action of running water capable of causing extensive denudation; also that we may well imagine, during some former suspension of eruptions on the eastern flank of the volcano, that ravines like the Cava Grande may have been gradually excavated in the wide space separating the two hills of Calanna and of Caliato.

In order to test the value of such an hypothesis, I determined to explore, from their

lower to their upper terminations, the two principal valleys of aqueous erosion which slope upwards from the foot of the cone to the southern margin of the Caldera.

Fig. 23.—*Furrows of aqueous erosion on the cone of Tengger* (from JUNGHUHN's 'Java,' vol. ii. part 2, p. 588).



Those who are conversant with JUNGHUHN's 'Volcanos of Java,' are well aware of the nature and value of this test; for they will remember that the flanks of volcanic cones which are in full activity are free from furrows eaten out by running water; whereas such as have been long extinct or are in a state of moderate activity, exhibit a great number of ravines, from 300 to 600 feet deep, excavated by torrents, and parted from each other by "ribs" or ridges of volcanic rocks, compared by JUNGHUHN to the spokes of an umbrella. All these furrows grow narrower and shallower when traced upwards, and come to an end before they reach the rim of the crater, as at *a*, *b*, in the great volcano called Tengger; whereas in such volcanic cones as have been truncated by explosions and subsidences, after considerable aqueous erosion, the rim is invariably indented, as would be the case if the line *c*, *d* represented the margin of such a cavity. On applying this test to Etna, I found that the crest of the southern escarpment of the Val del Bove, between the Montagnuola and Zoccolaro, was, as a general rule, very entire and unbroken, but that there were notches or abrupt depressions, several hundred feet deep, precisely at the two points where the upper ends of the valleys called the Val dei Zappini and the Valle del Tripodo (see Map, Plate L.) joined the crest. Hence it is natural to conclude that the valleys in question are of older date than the Val del Bove, and that their higher extremities were once prolonged towards the upper region of the cone, and were cut off when the Caldera was formed. Such an explanation, however, of the facts would be fatal to any theory which refers to a single catastrophe, or to any one mode of operation, whether slow or sudden, the upheaval of Etna, the tilting of the inclined beds, and the opening of the great cavity called the Val del Bove. The dividing "col" which parts the Valle del Tripodo, the largest of the two valleys above mentioned, from the Val del Bove, deserves the attention of every lover of the picturesque, as well as of every geologist, though my guides assured me that in their time they had never heard of its having been visited by any traveller. It may be reached from Zafarana without fatigue by the aid of mules in one day, returning in the evening. On one side of the narrow ridge, 6000 or 7000 feet above the sea, we look

back down a wooded and rocky alpine valley, while on the opposite or northern side, the wildest and most magnificent scenery of the Val del Bove lies at our feet. To our right are the precipices of the Serra del Solfizio extending to Zoccolaro; and to the left, the vast pinnacled and craggy promontories of rock, which jut out one behind the other, below the Montagnuola, presenting themselves in all their grandeur. Looking up, we see the summit of Etna with its wreath of white vapour streaming in the wind, while every other portion of the sky is a deep blue. The landscape is lighted up by a bright sunshine almost every autumnal morning, but soon after noon a body of fleecy clouds, formed first in the lower region, rises up slowly and rolls into the higher valley, hiding from view in succession the leading features of the scene, but disclosing from time to time some momentary glimpses of objects which had just vanished from the sight, until the whole are enveloped in one dense veil of mist.

In order fully to appreciate the depth and width of the two gaps made by the two valleys above alluded to, especially by the Valle del Tripodo,—breaks in the otherwise continuous southern rim of the Caldera,—it is necessary to look at them from a distance, or out at sea off Aci Castello. By their aid we see into the interior of the Val del Bove, from points where, but for these openings, that valley would be quite shut out from view.

The erosion of the Valle del Tripodo is still going on; and here we have an opportunity of studying a small inland delta at its mouth, and of learning by means of it how much matter has been brought down in a given time, or during the sixty-six years which have elapsed since 1792, when a powerful flow of lava crossed the lower extremity of the narrow valley and suddenly put a stop to all further transportation of alluvium to lower levels.

The waters of the torrent, even when most swollen, no sooner arrive at the margin of the lava, than they are instantly absorbed by its spongy, scoriaceous crust, and by the superficial rents and grottos in which it abounds. The engulfed waters continue their course underground, but the mud, sand, and boulders are all left behind, and already form a deposit, which may be called an inland delta (see the point marked "delta," Map, Plate L.). This deposit is several hundred feet long, 100 or more broad, and judging from the shape of the ground, 30 or 40 feet deep. It proves, on the one hand, how much erosion has gone on in little more than half a century; and on the other, how entirely all aqueous action ceases in areas once covered with fresh lava, and where a superficial drainage is turned into a subterranean one. The deep ravine-like valleys of S. Giacomo and Cava Secca, occurring about two and a half miles to the south-east of the Valle del Tripodo, may in like manner have been excavated by running water, and the process is still in full operation. Of this I became fully aware in October 1858, when, after heavy rains, I beheld the turbid waters which drain them rushing down like Alpine torrents, and saw and heard repeated avalanches of stones and mud descending from their steep sides, as well as from the precipices, in which they terminate abruptly at their upper ends; for they are not continued upwards, like the valleys of

Zappini and Tripodo above mentioned, as far as the margin of the Val del Bove. The origin of the neighbouring valley of Calanna is more doubtful. Although its head is closed in by a precipice called the Salto della Giumenta (fig. 10, p. 730), the cliffs of its southern side are prolonged in the upper part of Monte Zoccolaro, so as to join on to the southern escarpment of the Val del Bove. Perhaps there existed originally an upper valley of Calanna above the "Salto," before the external configuration and drainage of the old cone was totally altered by the formation of the Val del Bove. There may have been a fall of water, as there have been in modern times cascades of lava over the Salto, and such a fall may have hollowed out the valley by cutting its way backward as far as the precipice or Salto, just as the torrent of the Cava Grande is now causing its ravine to retrograde. If so, we may admit that other valleys may in like manner have furrowed the eastern slopes of the ancient cone between the hills of Calanna and Caliato, before the origin of the Val del Bove, in which case much alluvium would no doubt have been swept down to the sea or to its borders at that early epoch. But admitting the possibility of such erosion of early date, I nevertheless do not hesitate to attribute the bulk of the Giarre alluvium to the excavation of the Caldera itself, for reasons which will be more fully explained in the sequel.]

PLANT INSTIT LIBRA

[*Section of alluvium and basaltic lava between Giarre and La Macchia.*

In order fully to understand the question last alluded to, I must describe a natural section of the rocks laid open by the torrent descending from La Macchia to Giarre. This I examined in company with Dr. Mercurio and Signor G. G. Gemmellaro in 1857, and revisited it in 1858. We observed that the alluvium, attaining a thickness of 40 feet in the vertical banks of the torrent in the suburbs of Giarre (see above, pp. 709, 710), reposes on volcanic tuffs thinly stratified, which in some places emerge in low hillocks above the level of the alluvial terrace. As we ascended the dry bed of the stream, we saw first a current of lava capping the alluvium, and together with it forming the cliff of the right bank; then on the left, higher up, a powerful mass of basaltic lava, 90 feet thick, in great part columnar, resting on 30 feet of tuff, the perpendicular section being 120 feet high. The subjacent tuff, at its junction with the columnar basalt, is burnt red. At this spot the two formations are not separated by any intervening gravel, but further up on the right bank, a bed of alluvium, 10 feet deep, with many rounded and some huge angular fragments, 9 feet in diameter, is seen between the basaltic lava and the older tuff. From a study of the whole section, the details of which, if given here, would detain us too long, it appears that an ancient water-course, having the same general direction as that now passing by La Macchia, was first cut deeply in stratified volcanic tuff. This channel, narrow at first or near La Macchia, widened as it approached the present site of Giarre, where it spread out into an alluvial plain or delta. A current of basaltic lava flowing down from the higher region, and probably from the Val del Bove, then filled up the old channel, accumulating in some places to a depth of 90 feet, sometimes resting directly on the gravel-bed of the torrent, sometimes immediately on the tuff which rose

up from beneath the gravel and formed the steep sides of the ravine. In the course of time the waters again excavated a new channel, deeper than the first one, but not always coinciding with it in all its windings, although mainly in the same direction. This new erosion passed through both the basalt and subjacent tuff, with or without the intervention of the ancient river-bed, according as the new water-course corresponded with or deviated from the older one. Lastly, the lava of the year 1284, called the "Sciara di femina morta," flowed, as will be seen by the Map, Plate XLIX, from the Val del Bove west of Milo, and then north of Ballo to La Macchia, entering the modern channel of the torrent below that town, and is now in its turn cut through by the torrent, as I saw when I revisited the section in 1858. From this last fact I infer, that as this mediæval lava came down to this point from the Val del Bove, so many of the antecedent floods of melted matter, and among them the basaltic current above alluded to, was derived from that region. They would naturally all follow the lowest levels of the then existing surface of the country, just as the waters draining the eastern slopes of Etna have done. For this reason the older lava filled the old river-bed, and afterwards the newer lava of 1284 reached the existing river-channel.

We might have expected that what was once an ancient alluvial plain near the sea should now form a terrace at Giarre 40 or 50 feet above the level of the existing drainage, because the whole region must have participated in that upward movement, of which we find so many proofs along the sea-coast. During the gradual rise of the land the waters would hollow out their new bed, through gravel and incumbent lava, more readily than if the levels had been stationary. Upon the whole, I come to the conclusion that the drift of Giarre bears the same relation to the Val del Bove which the fluviatile conglomerate of the Barranco de las Angustias bears to the Caldera of Palma in the Canaries; that conglomerate of Palma is 800 feet thick and 4 miles long, composed entirely of fragments of volcanic rocks, and associated, like that of Giarre, with recent lavas of modern date*.]

[*How far successive subsidences and explosions cooperated in forming the Val del Bove.*

But we can by no means attribute the origin of the Val del Bove, any more than the Caldera of Palma, exclusively to the action of running water. In the case of the great Etnean cavity, the northern and southern escarpments are too widely separated from each other, and the western boundary cliff, or Balzo del Trifoglietto (nearly 4000 feet high), is too lofty to allow of such an hypothesis. Some one or more local catastrophes of paroxysmal intensity may have given rise to the first breaches, which ended in producing this enormous cavity, occupying about one-sixth of the circumference of the great cone, a cavity to which there is nothing similar on the other sides of the volcano.

What, then, we must now inquire, were the peculiar and exceptional causes to which it owed its origin? I have already spoken of the Cisterna, an elliptical cavity, now about 120 feet deep, produced in the year 1792 on the platform of the Piano del Lago

* See 'Manual of Geology,' by the author, 5th edit. p. 507.

by the sinking of the ground, and again deepened, according to M. E. DE BEAUMONT, by a subsidence in 1832. I also saw at a still higher level, near the Philosopher's Tower, a fosse-like depression, already half-filled up by recent showers of ashes which is known to have originated during the same eruption of 1832. The great rent of Mascalucia, formed in 1381, is still open, a mile in length and from 20 to 30 feet deep. Another fissure, 6 feet broad and of unknown depth, was formed in the plain of San Lio in 1669, and is said to have been 12 miles long, reaching to near the summit of Etna. Similar openings on the steep parts of a cone might easily become water-courses, and give passage to floods during the winter's rain and the melting of the snow, and these might gradually deepen and widen such fissures. But it is also fair to speculate on another very powerful agency, which in certain phases of volcanic activity, as Mr. SCROPE has frequently suggested to me, would scarcely fail to come into play,—I mean paroxysmal explosions, like that of Vesuvius in the year 79, wholly unaccompanied by any outpouring of lava. There were repeated eruptions of this kind in the history of Vesuvius for centuries after the year 79; and if a great explosion happened to be lateral instead of central, or on the slope instead of the highest point of a cone, the new chasm being commanded by higher ground or by the region of snow, floods of water would at certain seasons sweep down into it, and might increase its dimensions. To account for the position of so great a cavity on one side only of a cone, we may, in the case of Etna, imagine a connexion between the Val del Bove and the old axis of Trifoglietto. The ancient habitual duct or chimney, situated at T in the wood-cut map (fig. 14, p. 739), may, like that of the ancient Vesuvius after being plugged up for ages, have again given passage to vast volumes of pent-up gases or steam, blowing up the incumbent lavas of Mongibello, which had filled the crater and overtopped the secondary cone (as shown in fig. 15, p. 740). Moreover, the accumulated snow and ice, and consequently the action of running water, may at some earlier period have been greater in the higher region, when the cone of Mongibello was larger and loftier, before its truncation, especially if the first excavation of the Val del Bove dates as far back as the close of the glacial period, or when the Alpine glaciers reached the plains of the Po; for at that time the climate of a Sicilian winter could hardly fail to have been colder than now.

Isolated outliers of ancient rock, such as Finocchio and Musara, are striking monuments of waste, helping to prove the former continuity of the northern escarpment of the Val del Bove in a southerly direction; but unfortunately for the geologist, the foundations of these outliers are so much concealed by recent lava, that we cannot determine whether the removal of the missing rocks was brought about chiefly by aqueous agency, or by engulfment, or by explosions, or by a combination of two or more of these causes.

The multitude of dikes projecting from 10 to 50 feet above the general level of the ground in every part of the escarpments, shows clearly to what an extent the softer and more destructible beds have wasted away by atmospheric and torrential action. Such dikes are records of the former existence of masses of rocks now no more, though we can still trace the exact shape of the fissures by which they were at one period traversed.

The lateral ravines also, mentioned at page 754, bear testimony to the removing power of running water, since the Val del Bove was bounded by lofty precipices.

Even the torrent in the suburbs of Giarre, which is usually dry, and the channel of which slopes towards the sea at an angle of less than 4°, had in October 1857 carried to some distance fragments of stone 9 feet in diameter, derived from the older drift of its banks. What, then, may not have been the force of running water in the woody zone, where the mean fall is 7° or 8°, if the whole drainage of the eastern slope of Etna, instead of being as now subterraneous, was for a time superficial, after a suspension for some thousands of years of the flowing of lava?

We have already explained why, in the present state of the Val del Bove, no denudation on a large scale can take place. The obliteration from the map of Sicily of the river Amenano by the lava of 1669, is a good illustration of the antagonism of aqueous erosion and volcanic activity. Previous to 1669, the inundations of that river were often destructive of houses in Catania; but from the era alluded to, the waters have always made their way underground, and flow out clear and transparent from the extremity of the lava in the harbour of the great city. In like manner, at some former period there may have existed many rivers in the Val del Bove like those now draining the Calderas of Palma and Tiraxana in the Canaries, and like them they may, after uniting, have issued by one principal gorge; yet they would inevitably be all effaced from the map, and the gorge filled up with stony matter, whenever the time arrived, during a new phase of eruption, for fresh floods of lava to traverse the Caldera.]

Flood of 1755 *in the Val del Bove.*

The only well-authenticated instance of a great body of water having passed from the higher region of Etna through the Val del Bove to the sea, was in the year 1755. An eruption had taken place at the summit of the volcano in the month of March, a season when the top of the mountain was covered with snow. The Canon RECUPERO, a good observer and a man of great sagacity, was commissioned by CHARLES OF BOURBON, king of Naples, to report on the nature and cause of the catastrophe. He accordingly visited the Val del Bove in the month of June, three months after the event, and found that the channel of the recent flood, no less than two Sicilian miles broad, was still strewed over with sand and fragments of rock, to the depth of 40 palms*.

The volume of water in a length of one mile he estimated at 16 millions of cubic feet, and he says that it ran at the rate of a mile in a minute and a half for the first twelve miles. At the upper end of the Val del Bove, all the pre-existing inequalities of the ground, for a space of two miles in length and one in breadth, were perfectly levelled up and made quite even, and the marks of the passage of the flood were traceable from thence up the great precipice (or Balzo di Trifoglietto), to the Piano del Lago, or highest platform. RECUPERO, in his report, maintains that if all the snow on Etna, which he

* The *palm* in use in Sicily is $10\frac{14}{10}$ inches English: eight of these palms make one *canna*, and 720 canne one Sicilian mile.

affirms is never more than 4 feet deep (some chasms we presume excepted), were melted in one instant, which no current of lava could accomplish, it would not have supplied such a volume of water. He came therefore to the somewhat startling conclusion, that the water was vomited forth by the crater itself, and was driven out from some reservoir in the interior of Etna*.

It seems to me very unlikely that the Canon, who was on the ground within three months of the date of the catastrophe, should have been mistaken in regard to the region of the mountain whence the waters came. His conclusions on that head seem to have been legitimately deduced from the fact, that the wreck of the inundation was traceable continuously from the sea-shore at Riposto up to the highest cone or its neighbourhood. [I am therefore inclined to suspect that at the time of the eruption of 1755 there was upon the summit of Etna not only the winter's snow of that year, but many older layers of ice, alternating with volcanic sand and lava, at the foot or in the flanks of the cone, which were suddenly melted by the permeation through them of hot vapours, and the injection into them of melted matter. I stated in the first edition of my 'Principles of Geology,' that during my visit to Etna in 1828, I ascertained the existence of a glacier under lava near the Casa Inglese, on the S.E. side, near the base of the cone, and that it had been quarried during the previous summer, affording a supply of ice to the Catanians. On returning thirty years afterwards (September 1858), I found the same ice, a mass of unknown extent and thickness, still unmelted. It had been quarried only five years before to the depth of 4 feet on the very same spot. My guide told me that he had seen this mass of solid ice, the bottom of which they did not reach, and that it was overlaid by 10 feet of sand, and the sand again by lava.

If glaciers may thus endure for a series of years under volcanic sand and lava, the store of water which RECUPERO speculated upon as contained somewhere in the interior of the mountain, seems sufficiently accounted for. I am also now disposed to attach more importance than when I first wrote on this subject†, to the tales of the mountaineers, which RECUPERO thought worth recording. They related to him that the water was boiling, that it was as salt as the sea, and that it brought down with it sea-shells to the coast. Now it will be seen that the hypothesis above suggested would very naturally account for the water being hot, and it may have been impregnated with saline matter exhaled from fumeroles on the sides of the cone or from the crater itself during the eruption; and these exhalations, without giving to it the composition of sea-water, may have taken away its freshness. As to the story of the marine shells, if the flood, after issuing from the Val del Bove, cut deeply through the superficial lava or the alluvium between Milo and Giarre, it may possibly have reached a bed of subjacent newer pliocene clay at the height of 1000 or 1200 feet above the sea, washing out of it a great number of fossil shells of living species, strong enough to bear transportation as far as Riposto. But as the tertiary strata do not crop out anywhere at present in the region here alluded to, many of my geological readers will think it safer to ascribe this part of

* RECUPERO, Storia dell' Etna, p. 85. † Principles of Geology, 3rd edition, vol. ii. p. 123.

the statement of the peasants to a love of the marvellous, in which, after an event of so unusual a nature as this deluge, they might be pardoned for indulging.

An occasional flood like that of 1755 would no doubt do more towards filling up than towards excavating the Val del Bove, yet a repetition of such catastrophes, provided the outpouring of fresh lava was suspended, could not fail to exert a great denuding power, and would unquestionably give rise to just such deposits as those marked *a* on the map, Plate XLIX., which are so conspicuous near Giarre and to the southward.]

Gradual rise of the sea-coast and inland cliffs at the eastern base of Etna.

The position now occupied by the deposits of alluvium last alluded to (*a* and *a'*, Plate XLIX.), the upper portion of which have attained in some places a height of more than 400 feet above the sea, is the natural consequence of the upheaval of the whole coast along the eastern base of Etna, so often mentioned in the preceding pages. This gradual elevation was inferred many years ago by S. v. WALTERSHAUSEN, from the occurrence of raised beaches containing shells of recent species, and from lithophagous perforations in the rocks*, and he traced these signs of elevation to the northward of the volcanic region; as, for example, at the church of St. Andrea, below Taormina, where the limestone is bored by lithodomi at the height of 135 French feet above the sea, and where sea-shells of living species are preserved in a raised beach. Dr. CARLO GEMMELLARO also discovered in the same place horizontal grooves in the Jurassic limestone of the coast several yards above the sea-level, like those now worn by the beating of the waves on the rocks. His son also, Signor GAETANO, called my attention, during our visit to the Isle of Cyclops in 1857, to a marine breccia filling rents in the Newer Pliocene clay, in which I saw shells, many of them retaining their colour, of the genera *Columbella*, *Cypræa*, *Buccinum*, *Anomia*, *Patella*, and others, all of species now abundant in the neighbouring sea. Both the Gasteropods and Lamellibranchiates were recognized by Signor GEMMELLARO, as being in their normal position at various heights, some about 13 French metres above the sea, and a calcareo-siliceous incrustation of the same age contains the holes and shells of *Modiola lithophaga*. There are also large blocks of rolled lava, invested with Serpulæ, reaching points 14 metres high†. On the adjoining coast, at Trezza and at Molino d'Aci, we saw similar phenomena, to which S. v. WALTERSHAUSEN refers in the fifth and sixth parts of his 'Atlas' (pp. 6 and 7).

If such a bodily upheaval of the country has been going on for a considerable period during the subaërial growth of Etna, we are entitled to look for signs of ancient sea-cliffs, now inland at different elevations, and accordingly we meet with them, as before remarked, p. 710, one above the other, in ascending from Catania towards Nicolosi, where we find, first, a lower terrace cut in tertiary clay, and then a higher one at Fasano, where the old line of cliff has been excavated in stratified volcanic tuffs at the height of

* See a memoir by that author, entitled "Ueber die Vulkanischen Ausbrüche in der Tertiär-Formation des Val di Noto," Göttingen, 1846.

† Geol. Quart. Journ. 1858, vol. xiv. p. 504.

about 600 feet above the sea, the top of the cliff rising still higher, especially when traced in a north-easterly direction towards Licatia and beyond it.

[Other terraces have been cut in the gravel of the tract marked *a* in the Map, Plate XLIX., at various levels. When we pass from *a* to *a'*, or to the northern portion of the same alluvial region beyond Giarre and Riposto, we find the transported blocks individually smaller than on the coast nearer the Val del Bove, and the aggregate volume of the accumulation less considerable. On arriving at the river Menessale, still further north, we enter another hydrographical basin, where the pebbles consist in part only of Etnean lavas, the rest being of sandstone and other tertiary or secondary rocks, forming a mass about 30 feet thick, on the steep banks of the Menessale, where, as at Giarre, an elevation of the ancient alluvial plain has probably taken place.]

[*Alluvium of the northern, south-western and southern base of Etna.*

Leaving the Menessale, I made a tour, in 1858, round the base of Etna to examine the alluvium on all sides, going first along the northern foot of the mountain by Linguagrossa, Mojo, and Randazzo, where I found no alluvial terraces resembling those of Giarre. At Randazzo, however, I observed some indications of a change of level, on the right bank of the river Alcantara, where a lava-current of unknown date and of rudely columnar structure, has at some former period invaded the old channel of the river. That channel was first excavated in sandstone, and since the lava filled it, the Alcantara has cut out a new bed, 15 feet below the old one, giving us now on the right bank the following section: first and lowest of all, sandstone in regular and highly inclined strata*, forming the lower part of the bank for a height of 15 feet; 2ndly, above the sandstone the old river gravel, with well-rounded pebbles; 3rdly, the columnar lava, ending upwards in a terrace, having a nearly level surface. The whole scene reminded me forcibly of Auvergne, where torrents have been displaced by lava-currents, which have protected the ancient fluviatile gravel from destruction, even where the valleys have been re-excavated beyond their original depth. The isolated cone of Mojo, which rises at the northern foot of Etna, and is supposed to have been formed about four centuries before the Christian era, but which, according to S. von Waltershausen, is of uncertain date, stands in the river-plain of the Alcantara, just as the cone of Tartaret and some others in Auvergne occupy the alluvial plains of the existing rivers, and, like them, has sent forth its stream of lava, since much denuded by the running waters.

Passing from Randazzo to Maletto and Bronte (see Map, Plate XLIX.), we observe nothing on the surface of the western flank of Etna but recent lavas; but turning to the south-west, and travelling by Adernò, Biancavilla, and Licodia, we enter the ancient basin of the Simeto, once evidently more extensive than now, its northern margin having been elevated many hundred feet above its original level. That margin, at a time when

* In these older sandstones, and some associated conglomerates and marls, whether at Randazzo or on the side of Bronte and Licodia, I could find no fossils. Hoffmann has given to them the general name of Apennine formations, comprising in that term the whole cretaceous and eocene series.

Etna was a volcano of smaller dimensions, was first overspread with alluvium, consisting of well-rounded pebbles of sandstone and other non-volcanic rocks, intermixed with a few of igneous origin, and afterwards overflowed by currents of lava, which still rest on the old gravel. The superimposed lavas, often rudely columnar, are now seen running out in long terraces from the south-western base of the great cone, and ending abruptly in cliffs which face the valley of the Simeto. Thus, for example, in the escarpment facing south-west between Biancavilla and Licodia, we observe above the fundamental rocks of sandstone and marl, first, a bed of pebbles resting unconformably on those ancient rocks; and 2ndly, the incumbent and semi-columnar dolerite.

Passing thence by Paternò and Misterbianco to Catania, we find still more conclusive evidence that the ancient littoral and delta-deposits of the Simeto and its tributaries have been upraised to very considerable heights above their original level, by movements which have also elevated the subjacent modern tertiaries in the country called the Terra Forte, south and west of Catania (see Map, Plate XLIX.). These same tertiaries, as we shall see in the sequel, also crop out along the eastern base of Etna, and contain marine shells, of which nearly nineteen-twentieths belong to species still living in the Mediterranean. The farther we recede from the southern foot of Etna towards the channel of the Simeto, the more dense become the accumulations of upraised pebbles. At Misterbianco, which I visited in company with Signor Gravina, they attain a thickness of 150 feet, and form the capping of hills, more than 600 feet above the sea-level. They are entirely different in shape and composition from that alluvium of exclusively Etnean origin, with angular fragments, occurring at *a a'* of the Map, Plate XLIX., for they consist of perfectly rounded pebbles of quartzose grit, nummulitic limestone and sandstone, fissile clay-slates, granite, gneiss, mica-schist, and a variety of other rocks, with a very moderate admixture of basalt*.

Some of the boulders of basalt, and some of those composed of hard tertiary grits, are 3 feet and upwards in diameter, but they are always well-rounded. They have evidently been derived from rivers which drained the western and central parts of Sicily, far beyond the precincts of Etna.]

[*Volcanic eruptions in the alluvial plain of the Simeto.*

At La Motta and Paternò we find within the area of the ancient estuary some highly interesting monuments of local volcanic eruptions, posterior in date to the great alluvium, for they have cast up some of the pebbles, so that they are enveloped in tuff or in lava, and often much burnt and altered. At La Motta, the summit of a basaltic and tufaceous hill thus formed is more than 900 feet high above the sea. The sites of this and of other local outbreaks in the same region are well laid down by Hoffmann in his Geological Map of Sicily. They were probably coeval with the earlier subaërial eruptions of the cone of Etna and with the tuffs of Fasano, of which I shall presently speak.

I have alluded particularly to the eruptions of La Motta and Paternò, because as they

* See a memoir by Signor B. Gravina, Bulletin de la Société Géol. de France, vol. iv. p. 403, 1858.

have burst out through tertiary clays covered with alluvium, no other changes have since occurred in the same region except those produced by fluviatile denudation, which, by removing a portion of the volcanic and other rocks, has enabled us to understand the relation of the former to the older formations. Here, therefore, we have an opportunity of testing the value of a speculation often hazarded by certain geologists, who wish to adopt, in a modified form, the theory of Elevation-Craters. They contend that however problematical the assumed terminal catastrophe may be, still the incipient convulsion must at any rate heave up the ground all round the orifice of eruption, and make the beds dip away in every direction from a central point, after which the new lavas and scoriæ as they were thrown out might mantle round the first-raised nucleus. But we find no warrant for such conjectures in the hills of Paternò and La Motta; nor did I see any in the more numerous sections of the volcanic and accompanying sedimentary rocks which I examined in 1828 in the Val di Noto, south of the plains of the Simeto. Yet the volcanos of that part of Sicily have burst out through marine tertiary formations horizontally stratified, and admirably fitted for upheaval into dome-shaped hills with crateriform openings at the top, if it were the nature of volcanic forces so to distend, lift up, and burst open the rocks which they inject. Instead of this, the melted matter seems to have simply made its way upwards through fissures, now constituting dikes, without producing any extraordinary dislocation of the rocks, and without making them dip at steep angles away from a central axis.]

[*Upraised fluviatile and marine deposits of the old estuary of the Simeto.*

The proximity of the land to the old estuary deposit of the Simeto is indicated by the tusks and teeth of elephants* found near Paternò, as well as at other places in the "Terra Forte" south of Catania, and frequently in digging the foundations of that city. Bones also of the horse, and of several species of bovine animals, and the teeth and horns of stags have been met with in the same places. I was also informed, that in the old alluvium of Cefali the molar of a hippopotamus had been found; but I had no opportunity of verifying these facts, or of getting the species determined by competent osteologists.

Signor B. Gravina, in a memoir recently published in the 'Bulletin' of the Geological Society of France (2nd series, tom. xv. p. 391, 1857–58), has recorded the discovery of a member of this same series of estuarine deposits which is of marine origin. He took me to see its exact position in 1858, in the neighbourhood of Misterbianco, where it is covered by the conglomerate. It consists of ferruginous sands and clays, which in the hill of Camuliu, between Misterbianco and Catania, contain a bank of oysters of a recent species (*Ostrea foliacea*), together with *Pecten varius* and *Anomia ephippium*. These marine sands rise to the height of more than 800 feet above the sea, while the neigh-

* The fossil elephant above alluded to is probably *Elephas antiquus*, Falconer. To that species, Dr. Falconer informs me (March 21, 1859), all the elephantine remains found in caves near Palermo, or between that city and Trapani, are referable, no vestige of *E. primigenius* having been seen by him in Sicily.

bouring hill of Cardillo, which is 900 feet high, is capped by old alluvium or conglomerate, having there a thickness of 60 feet. The height of such modern (and probably post-pliocene) formations, at the distance of about twenty-five English miles from the centre of Etna (or axis of Mongibello), has an important bearing on the theory of Elevation Craters, for some geologists have wished to connect the upheaval of the marine tertiary clays skirting the base of Etna, with movements supposed to have given rise to the cone itself and to the high inclination of the volcanic rocks; whereas the upheaval in question evidently extended to the plains of the Simeto in a southern, and, as we have seen before, to Taormina in a northern direction, and was rather of the nature of those movements by which great continents have been raised above the level of the sea.]

Leaf-bearing tuffs of Fasano near Catania.

It is probable that a portion of Etna which is of subaërial origin is coeval with the upraised alluvial and estuarine formations last mentioned, and that a still larger portion of the mountain is of posterior date. We find immediately north of Catania the marine tertiary clays and sands of Cefali, of the Newer Pliocene period (250 French feet above the sea), covered with alluvium resembling that of the Simeto, and at Fasano, at a height of more than 600 feet, the same clays are overlaid by tuffs of subaërial origin. Imbedded in these tuffs are found not only boulders of basalt, but well-rolled pebbles of sandstone and grit, identical with those of Misterbianco and other localities in the basin of the Simeto. The tuffs of Fasano, which are of considerable thickness, contain in abundance, as do the same beds at Licatia not far distant, the leaves of terrestrial plants, some of which I collected myself on the spot, and others were liberally presented to me by Signor Gravina and Professor Tornabene. As these fossils are the only ones yet obtained from the subaërial deposits of Etna, I was very desirous of having them carefully determined by a botanist of high authority, and accordingly submitted them to Professor Heer of Zürich, who has had the kindness to give me both drawings and descriptions of them, which will be found in the Appendix, p. 782, and in Plate LI. It appears from his examination of the best-preserved specimens, that three of the fossils may be identified with three living species, all indigenous to Sicily; namely, 1st, the *Laurus nobilis*, or Sweet Bay; 2ndly, *Myrtus communis*, or Common Myrtle; and 3rdly, *Pistacia lentiscus*, or Mastic Tree. To fix the age of these tuffs relatively to the mass of Etna, would be difficult, because they have been carried up gradually above their original level at the same time that the cone has been growing in size and height, and encroaching with its lavas on the area previously occupied by tuffs, and by the underlying tertiary clays. But I presume that these plants of Fasano flourished after the marine sands and clays of Camaliu were formed, and during or immediately after the period of the upraised alluvium or conglomerate of Misterbianco. They may therefore have been contemporaneous with the eruptions of La Motta and Paternò.

At Fasano these plant-bearing tuffs are very regular in their stratification, and dip at an angle of 11° towards the north-west, or directly towards the cone of Etna, an incli-

nation probably due to subsequent movements, and if so, exactly the reverse of that which the theory of a central upheaval capable of lifting up the cone of Mongibello would require.

Age of the Marine Tertiary Strata of Cefali, Catira and Nizzeti.

In order to determine within certain limits the geological age of the principal mass of Etna, we must endeavour to ascertain the true chronological place in the tertiary series of those marine strata which at various points along the eastern base of the mountain crop out from beneath the subaërial volcanic rocks.

I have already alluded to the occurrence of such fossiliferous clays in the district called "Terra Forte" immediately south of Catania, where they must have emerged from beneath the sea at a very modern period, because the hills composed of them are capped at the height of nearly a thousand feet, not only by unconformable alluvium, but by formations of about the same age as the alluvium containing recent species of marine shells. We again meet with clays like those of the Terra Forte, replete with fossil shells at Cefali in the northern suburbs of Catania, and find that in that place also they are covered unconformably by alluvial deposits like those of the Simeto, proving by their present elevated and insulated position that a considerable change has taken place in the physical geography of the country since they originated. At a short distance north of Cefali, we come to the inland cliff of Fasano, at the base of which we again observe the tertiary clay, while in the cliff itself are seen the overlying plant-bearing tuffs before mentioned, with imbedded pebbles, like those of the alluvium of the valley of the Simeto. When the Fasano cliff was formed, we must suppose the sea or the waters of the ancient estuary to have beat against its base, causing denudation, to which the tuffs could never have been exposed after they had once attained their present level (about 600 feet above the sea), and when the surrounding country had assumed its present configuration.

The most inland place, within the boundary of the volcanic region of Etna, where the tertiary strata crop out, is Catira, about two English miles N.N.E. of Fasano and four north of Catania, a point at which they also reach their greatest altitude, ascertained by S. v. Waltershausen to be 1180 French, or 1258 English feet above the sea.

I visited Catira in company with Signor Gravina and Signor Gaetano G. Gemmellaro in 1858. The last-mentioned geologist pointed out to me in the tertiary clay and sand, several pebbles of volcanic rock with serpulæ attached, implying that the strata were originally of littoral origin, and that some volcanic formation not only pre-existed, but had emerged in the neighbourhood so as to undergo some waste and supply pebbles to an adjoining beach.

At Catira these tertiary strata form three hills, capped with doleritic lava,—hills which are not due to any local movements of upheaval, but to the action of the sea, probably at the time when they were gradually emerging from the deep. Such eminences may once have formed a group of islands off the shore, as the Fariglioni or

Cyclopean islands do now, and in this manner we may explain the steep cliffs which they present in every direction, some facing landward and others seaward.

In order to understand geographically the other localities where the tertiary fossiliferous clays crop out at the base of Etna, we must return to Catania, and follow the coast which trends in a north-east direction (see Map, Plate XLIX.). There they first present themselves at Aci Castello, then again at Trezza opposite the Cyclopean Isles, and again a mile and a half north-west of that place, and about as far from the sea, at Nizzeti. At all these points, the marine clays and sands, sometimes reaching elevations between 500 and 600 feet above the sea, are associated with contemporaneous basaltic and other igneous products, the most ancient monuments of volcanic eruptions within the region of Etna.

During my first visit to Sicily in the year 1828, I collected at two of the above mentioned localities (Trezza and Nizzeti) as many fossil shells as I could then find, and submitted them to M. DESHAYES of Paris, who referred them to sixty-five species, the names of which I published in the Appendix (p. 53) to the third volume of my 'Principles of Geology,' which appeared in 1833. I then stated (p. 79), as the result at which the eminent French conchologist had arrived, "that almost all the shells were identical with species now inhabiting the Mediterranean, and for the most part now frequent on the coast immediately adjacent."

A few years later Dr. PHILIPPI visited Sicily, and in his 'Enumeratio Molluscorum Siciliæ,' published in 1836, gave lists of the shells found by him at Nizzeti and Cefali. From the first of these localities he obtained seventy-six species, four only of which he regarded as extinct, including *Murex vaginatus*, which I have now ascertained to be a living species. In his list of 109 shells from Cefali he marks eight as extinct, from which also we must deduct *Murex vaginatus*, so that according to his investigations the proportion of extinct is in the case of Nizzeti only four in the hundred, and about six in the case of Cefali.

On the occasion of my last visits to Catania in 1857 and 1858, I had the good fortune to make the acquaintance of Dr. ARADAS, an eminent physician and naturalist, who possesses the finest collection yet formed of the Nizzeti shells, which he liberally placed at my disposal, allowing me to take them to Paris and London. At Paris I obtained once more, after an interval of thirty years, the kind assistance of my friend M. DESHAYES, in determining the names of fossils from Mount Etna, consulting him especially on points on which Dr. ARADAS had entertained doubts. With one or two corrections, I have printed in full, in the Appendix B, p. 783, this list, as drawn up by Dr. ARADAS. He has indicated therein the relative abundance of each species, also which of them are extinct, or not at present known in the Mediterranean. The total number of species being 142, sixty-seven are marked as additions to PHILIPPI's list from the same place. *Murex vaginatus* was given as extinct, it having been so regarded by PHILIPPI; but M. DESHAYES first informed me (October 1858) that he had seen a shell from the Mediterranean, which he believed to be identical, and Mr. CUMING has since shown me three

fine specimens in a fresh state not differing in the slightest particular from the Nizzeti fossil*.

Omitting this shell, we have eleven species out of 142 which are extinct; but when we endeavour to estimate the relative age of this formation, we must take into account not only the comparative number of living and extinct species, but also the relative number of individuals by which each species is represented. We then find that although the ground in most of the localities above enumerated is plentifully strewed over, especially after it has been washed by heavy rains, with fossil shells, not one of the extinct species, except *Buccinum semistriatum*, is met with in abundance. *Buccinum musivum* is rare; and as for the other nine, they are so excessively scarce, that most of them, if not all, are only known as yet by single individuals. It is true that the same may be said of some few even of the recent species, but the larger proportion of that class are very common. I never succeeded, when collecting myself at Cefali, Aci Castello, Trezza, and Nizzeti, during my three visits to Etna in 1828, 1857, and 1858, in picking up with my own hands any of the extinct species, except *Buccinum semistriatum* and *B. musivum*.

In regard to two others of the eleven shells enumerated by Dr. ARADAS as extinct, namely, *Pyrula rusticola* and *Monodonta elegans*, FAUJ., of each of which single individuals only, and those not in a perfect state, have been found, M. DESHAYES observed to me that they agree perfectly in form and appearance with well-known Miocene fossils which he has received from Bordeaux; he therefore asked whether some mistake may not have been made, or if not, whether they might not have been washed out of an older tertiary formation in the neighbourhood and imbedded in the Nizzeti clays. In answer to this latter suggestion, it would, I think, be difficult so to explain away their presence; for the only other strata which I saw containing tertiary shells near the base of Etna occurred at the distance of about fifteen miles from Nizzeti, nearly due north, on the banks of the river Menessali, about three miles W.S.W. of Piedemonte. Here I obtained a sufficient number of species to satisfy me that the strata were older than those of Nizzeti and Cefali, although by no means referable to the Miocene era, but belonging rather to some Newer Pliocene beds, more ancient than the clays of Nizzeti.

In the Appendix C. (page 786) will be found a second list of 62 species of Mollusca and 3 Echinoderms from Catira, above mentioned, p. 777, given me by Signor GAETANO G. GEMMELLARO, by whom they were collected and named. Excluding five of the species of mollusca, which Signor GEMMELLARO could not determine specifically, there would

* *Murex vaginatus* is one of the few species on which some Italian geologists have relied for proving the antiquity of the marls of the volcanic island of Ischia, near Naples, to be much greater than that which I assigned to them after my visit to Naples in 1828. (See Bulletin de la Soc. Géol. de France, tom. xi. 2nd ser. p. 72, and tom. xiii. p. 285, and xxv. p. 362.) In the first edition of my 'Principles of Geology,' I classed these marls as Newer Pliocene (see Table, vol. iii. p. 61 and p. 126), and having re-examined Ischia in 1857, I maintain the correctness of my published opinion, namely, that these greenish and bluish marls, about 1700 feet above the sea, belong, like the sub-Etnean marine clays above described, to the newest part of the Newer Pliocene period. To class them therefore as *sub-Apennine* or Older Pliocene, would be a serious retrograde movement, and one against which I am glad to see that M. PUGGAARD has protested. Bulletin, 2me sér. tom. xiv. p. 336.

remain 57 species, of which five are extinct; a proportion of about 9 per cent., implying a somewhat greater divergence from the recent fauna than the other lists. One also of the three echinoderms, *Brissus cylindricus*, is only known as fossil; but as I have had no opportunity, aided by skilful conchologists, of comparing the fossils themselves named in this list with the large collections in the Museums of Paris and London, I am not sure that the Catira fossils, if subjected to a similar scrutiny, would not yield results in more exact harmony with those obtained from other localities. Signor GEMMELLARO himself stated to me, that not only do the majority of the Catira shells agree specifically with those now living in the Sicilian seas, but the individuals are of the same average size and aspect, which is not the case with those found fossil in some of the older tertiary formations in Sicily.

Modern date of the mass of Etna.

If asked to which of our British tertiary strata those of Nizzeti and Cefali approach most nearly in age, I have no hesitation in answering, the Norwich Crag; but the latter formation is probably the older of the two, its fossils appearing to diverge somewhat further from the fauna of our British seas, than do the shells of the Etnean localities above mentioned from the mollusca now inhabiting the Mediterranean. If so, the great mass of Etna, or all that is of subaërial origin, being newer than the Nizzeti clays, must be, geologically speaking, of extremely modern date. Its foundations were probably laid in the sea; and were in all likelihood contemporaneous with the basalts and other igneous products of the Cyclopean Isles and Aci Castello, which, as we have stated, belong to the period of the fossil shells of Nizzeti and Cefali. When that fauna flourished, the area where Etna now rises was probably a bay of the sea, afterwards converted into land by the outpouring of lava and scoriæ, as well as by the slow and simultaneous upheaval of the whole territory. During that gradual rise the ancient river-plain of the Simeto, in which were imbedded the remains of the elephant and other quadrupeds, together with certain marine strata (those of Camuliu) formed near the mouth of that river, acquired their present comparatively elevated position. The local eruptions of La Motta and Paternò took place about the same time, *i. e.* during or immediately after the deposition of the older alluvium, when also the leaf-bearing tuffs of Fasano were formed. In the course of the same long period of elevation, the cone of Trifoglietto, and probably the lower part of the cone of Mongibello, were built up. Still later the cone last mentioned, becoming the sole centre of activity, overwhelmed the eastern cone, and finally underwent in itself various transformations, including the truncation of its summit and the formation of the Val del Bove on its eastern flank. At length the phase of lateral eruptions, which is still in full vigour, closed this long succession of events—changes which may have required thousands of centuries for their development, although in the same lapse of time the molluscous fauna of the Mediterranean has scarcely undergone a twentieth part of one entire revolution.

We have seen that almost all the common shells of Nizzeti are of living species; but this is still more true of the fossil shells of the glacial epoch in Northern Europe and

America, which are nearly all, if not all, identical with mollusca still inhabiting the northern hemisphere. Notwithstanding which, a large part of the European area has been turned from sea into land, or from land into sea, since the commencement of that glacial period, while the present distribution of living species of plants and animals throughout the continents and islands has been entirely established since the time when the transportation of erratic blocks by ice took place.

Recapitulation of PART III., *and concluding remarks on "Craters-of-elevation."*

Having recapitulated, at pages 737 and 761, the principal conclusions arrived at in the first and second parts of this memoir, I shall now give a brief summary of those which I have endeavoured to establish in this third part.

1st. Some valleys or ravines were formed by aqueous erosion on the flanks of Etna before the existence of the Val del Bove, nevertheless a large proportion of the transported materials at the eastern base of the mountain was accumulated during the formation of that valley, which was in part due to aqueous erosion.

2ndly. The first depressions in which the Val del Bove originated may have been due to the sinking in of the ground, and also to lateral and paroxysmal explosions unaccompanied by the emission of lava.

3rdly. A gradual upward movement of the coast has carried up to considerable heights the more ancient alluvial formations at the eastern and southern base of Etna, together with the subjacent marine tertiary strata; and this movement continued down to very modern times, and perhaps still continues.

4thly. The alluvial deposits of the valley of the Simeto were both marine and fluviatile, the latter containing some remains of extinct terrestrial animals, but the whole probably of post-pliocene date, and coeval with the subaërial portion of Etna.

5thly. All the shells of the tertiary strata of the eastern base of Etna, which are abundant, belong, with one or two exceptions, to species now living in the Mediterranean, and the newer pliocene strata, in which they are imbedded, were probably coeval with the oldest foundations of Etna.

6thly. In certain tuffs, next in age to the older and most highly elevated alluvium, the remains of terrestrial plants of recent species occur.

Lastly. No connexion whatever can be traced between the *general* movement of upheaval which has accompanied the growth of Etna, and the conical or dome-like form of the mountain; and even where local eruptions have burst through the tertiary and alluvial strata, these last have not been lifted up in such a manner as to favour the hypothesis of craters of elevation.

Reverting now, in conclusion, to the phenomena described in Part I., by which the capability of lava to consolidate on steep slopes, and to form thereon continuous and tabular masses of crystalline rock, is demonstrated, I may observe, that we can henceforth dispense with the sudden and terminal catastrophe to which the leading dogma of a certain school of geologists would, if adopted, force us to resort, in order to account for the highly inclined beds in every large volcano. The chief question which still

remains to be worked out is, how far each mountain of igneous origin, whether having a double axis like Etna, or a single one like Vesuvius, may owe a part of its conical or dome-like form to a gradual distension of the mass brought about by the injection into it of many, and sometimes voluminous, dikes of melted matter; also how far the same agency may impart to the tuffs and lavas a steeper inclination than that which they had originally. The answer to such inquiries may perhaps be different in each separate cone; but whether one-fifth of the inclination, as I have suggested as possible in the case of Etna, or a greater or less amount be ascribable to this cause, I have come to the conviction that upheaval has nowhere played such a dominant part in the cone and crater-making process, as to warrant the use of the term "elevation-craters," instead of cones and craters of eruption. Such a designation, as well as the theory implied by it, would be alike inappropriate in the case of all the igneous mountains which I have seen, whether in Sicily or the Phlegrean Fields, or in the volcanic district of Rome or that of Central France, or lastly, of Madeira and the Canaries.

APPENDIX.—A.

REMARKS ON THE FOSSIL PLANTS FROM THE VOLCANIC TUFF OF FASANO NEAR CATANIA ON MOUNT ETNA, *extracted from a letter addressed to the author by Professor* OSWALD HEER, *of Zurich, dated April* 1858.

The leaves from the volcanic tuff of Etna belong to three species now living in Sicily, namely, *Laurus nobilis*, L., *Myrtus communis*, L., and *Pistacia lentiscus*, L.: the myrtles and laurel leaves are the commonest, and are probably those which you mention as having been mistaken for those of *Quercus ilex*, L.

DESCRIPTION OF THE SPECIES.

1. *Laurus nobilis*, L., fig. 3, Plate LI.—Several leaves, exactly agreeing with the living species. Leathery leaves, narrowing at the base into the leaf-stalk, border entire or sometimes wavy, the secondary nerves arched, the bodies of the leaves filled with a distinct network.

Easily to be distinguished from *Quercus ilex* by the narrowed base towards the leaf-stalk and the nervation.

2. *Myrtus communis*, L., figs. 4 and 5, Plate LI.—The most numerous of the leaves from Fasano. They have completely the characteristic nervation of myrtle leaves, a distinct border nerve, which runs parallel to the edge, and receives the numerous delicate secondary nerves. Here and there the nervillæ may also be detected. The secondary nerves appear to be rather more numerous than in the living myrtle.

There are two principal divisions:—

a. Fig. 4, Plate LI.—Leaves agreeing in size and form with the large-leaved myrtle of Italy and of our greenhouses. They are also pointed at the end.

b. Fig. 5, Plate LI.—The others, on the contrary, are much larger, and sometimes blunt at the end, such as are found in myrtles kept in greenhouses and wet soils. But

a distinct species cannot be made out of these large leaves, as they entirely agree in nervation with the others. These large leaves attain a length of 2 inches and a breadth of 1 inch, while the smaller ones are only 1 inch long by ½ inch broad. The secondary nerves run almost parallel, and with a slight curve to the border nerve, and run into it at almost right angles. In the middle of the area they have a shortened secondary nerve, which over two-thirds of this area runs into a network. The border nerve is quite as strong as the secondary nerves; but the middle nerve, or midrib, is much stronger.

It is striking, that the secondary nerves are rather more distinct than in the living myrtle leaves; and this is in like manner the case in the leaves represented in nature-printing.

Here and there are seen fine dots close together which appear to belong to the leaf.

3. *Pistacia lentiscus*, figs. 1 and 2, Plate LI.—Several beautiful pinnated leaves. The general leaf-stalk is in some distinctly winged, while in others it is hardly to be observed. That this winged border has not always been preserved, is proved by the circumstance that it sometimes exists on one side and is wanting on the other. The stalk lies below this and forms a furrow, whilst the winged borders stand out a little or are placed slanting against the stalk. The leaves alternate, though for the most part nearly approximating; on each side four, rarely five, the end leaves wanting. The leaves are leathery, sessile, elliptical or long elliptical, narrowed at the base, somewhat inequilateral, generally the upper side narrower than the lower, as in *Pistacia lentiscus*. From the midrib proceed very delicate curved secondary nerves, which are frequently effaced. The size of the leaves varies from 7 lines in length and 3 lines in breadth, to as much as 14 lines in length and 5½ lines in breadth. The edge of the leaves generally curled, and agreeing with the leaves of *Pistacia lentiscus*,—1st, in the leathery structure of the surface of the leaf; 2ndly, in the number and position of the leaflets; 3rdly, in the form of the sessile leaves; 4thly, in the winged leaf-stalk (in the living species the breadth of the wing-border is very variable); 5thly, in the nervation; and 6thly, in the rolled edge of the leaf.

I think, therefore, I have good ground for referring these leaves to the Mastic tree, although I was a long time in doubt about them.

B.

[List of Fossil Shells from Nizzeti near Aci Castello, found by Professor Andrea Aradas (see p. 778).

N.B. *The species marked with an asterisk are those which do not appear in the list published by* Philippi *in his 'Enumeratio Molluscorum Siciliæ,'* vol. ii. p. 262.

The species printed in italics are extinct, or not known as living.

Mactra triangula, Ren.; common.
*Mactra solida, L.; very rare.
Corbula nucleus, Lamk.; very common.
*Diplodonta apicalis, Philip.; very rare.
Tellina distorta, Poli; very rare.
*Lucina spinifera, Montag.; rare.

Astarte incrassata, BROCC.; very common.
Cytherea Chione (Venus), L.; rare.
*Cytherea multilamella, LAMK.; rare.
*Cytherea exoleta (Venus), L.; rare.
*Cytherea rudis, POLI; common.
*Cytherea Cyrilli, SCACC.; rare.
Venus fasciata, DONOV.; common.
Venus verrucosa, L.; rare.
Venus radiata, BROCC.; very common.
*Venus gallinula, LAMK.; very rare.
*Venus gallina, L.; rare.
Cardium echinatum, L.; rare.
Cardium papillosum, POLI; very common.
Cardium lævigatum, L.; rare.
*Cardium sulcatum, LAMK.; rare.
*Cardium tuberculatum, L.; common.
Cardita aculeata, POLI; rare.
Cardita corbis, PHIL.; very rare.
Arca lactea, L.; rare.
Arca diluvii, LAMK.; very rare.
*Arca navicularis, BRUG.; rare.
Pectunculus glycimeris, LAMK.; rare.
Pectunculus pilosus, LAMK.; common.
Pectunculus violacescens, LAMK.; rare.
*Pectunculus nummarius (Arca), BROCC.; very rare.
Nucula sulcata, BRON.; common.
Nucula margaritacea, LAMK.; common.
*Nucula placentina, LAMK.; very rare.
*Nucula emarginata, LAMK.; very rare.
*Modiola lithophaga, LINN.
*Lima squamosa, LAMK.; very rare.
Pecten Jacobæus, L.; rare.
Pecten maximus, L.; very rare.
Pecten opercularis, L.; rare.
Pecten polymorphus, BRON.; common.
Pecten aspersus, LAMK.; very rare.
*Pecten varius, LAMK.; rare.
*Spondylus aculeatus, CHEMN.; very rare.
*Ostrea cochlear, POLI; rare.
*Ostrea plicatula, L.; rare.
Anomia ephippium, L.; rare.
*Anomia margaritacea, POLI; very rare.
*Patella Rouxii, PAYR.; rare.
*Patella ferruginea, GMEL.; rare.
*Patella cærulea, L.; rare.
*Pileopsis hungarica, LAMK.; rare.
Calyptrea vulgaris, PHIL.; common.
Rissoa oblonga, DESM.; rare.
Rissoa calathiscus, LASKEY; rare.
Rissoa Montagui, PAYR.; rare.
Rissoa Bruguieri, PAYR.; rare.
Natica millepunctata, LAMK.; common.
Natica sordida, SWAINS.; common.
Natica macilenta, PHIL.; rare.
*Natica olla, M. DE SERRES; rare.
*Natica intricata, DONOV.; rare.
*Natica Dilwynii, PAYR.; common.
*Natica Guillemini ?, PAYR.; rare.
*Siliquaria anguina (Serpula), L.; very rare.
Scalaria planicosta, BIVONA; very rare.
*Scalaria communis, LAMK.; rare.
Vermetus subcancellatus, BIVON.; rare.
Vermetus glomeratus, BIVON.; very rare.
*Fossarus *siculus* (Maravignia *sicula*), ARADAS; very rare.
*Solarium stramineum, GMEL.; very rare.
Trochus conulus, L.; rare.
Trochus striatus, L.; rare.
Trochus rugosus, L.; common.
Trochus sanguineus, L.; very rare.
Trochus magus, L.; rare.
Trochus fanulum, GM.; rare.
Trochus Guttadauri, PH.; very rare.
*Trochus fragaroides (Monodonta), LAMK.; rare.
*Trochus divaricatus, L.; rare.
*Trochus crenulatus, BROCC.; rare.
*Trochus articulatus (Monodonta), LAMK.; rare.
*Trochus *dubius*, ARAD.; very rare.

*Trochus Adansonii, PAYR.; rare.
*Monodonta elegans, FAUJ.†
Monodonta Jussieui, PAYR.; rare.
*Monodonta corallina (Trochus), L.; rare.
*Monodonta Vieilloti, PAYR.; rare.
*Monodonta Tinei-Calcara, ARAD.; very rare.
Turritella communis, RISS.; very common.
Cerithium vulgatum, BRUG.; rare.
Cerithium lima, BRUG.; rare.
Pleurotoma gracile, MONT.; rare.
Pleurotoma Vauquelini, PAYR.; rare.
*Pleurotoma undatiruga, BIVON.; very rare.
*Pleurotoma volutella, VALENC.; very rare.
*Pleurotoma elegans, SCACC.; rare.
*Cancellaria cancellata (Voluta), L.; very rare.
*Cancellaria *cassidea* (Voluta), BROCC.; very rare.
*Cancellaria *coronata*, SCACC.; very rare.
*Fasciolaria lignaria (Murex), L.; rare.
Fusus rostratus, OLIVI; rare.
Fusus craticulatus (Murex), BROCC.; common.
Fusus echinatus, SOWERBY; rare.
*Fusus lamellosus (Murex), DE CRISTOF. and JAN; rare.
*Fusus corneus (Murex), L.; rare.
*Pyrula *rusticula*?, BAST.; very rare.
Murex cristatus, BROCC.; rare.
Murex Edwardsii, MENK.; rare.
Murex vaginatus, DE CRISTOF. and JAN; rare.
Murex Trunculus, L.; rare.
*Murex Brandaris, L.; rare.
*Murex erinaceus, L.; rare.
*Murex *multilamellosus*, PHIL.; very rare.
*Ranella lanceolata, MENK.; very rare.
*Triton cutaceum, L.; very rare.
*Triton corrugatum, LAMK.; rare.
*Triton intermedium (Murex), BROCC.; very rare.
*Chenopus pes-pelecani (Strombus), L.; very common.
*Cassidaria tyrrhena (Buccinum), L.; rare.
Buccinum prismaticum, BROCC.; common.
Buccinum *musivum*, BROCC.; rare.
Buccinum ascanias, BRUG.; rare.
Buccinum variabile, PHIL.; rare.
Buccinum mutabile, L.; common.
Buccinum *semistriatum*, BROCC.; very common.
Buccinum neriteum, L.; rare.
Buccinum scriptum, L.; rare.
*Buccinum *striatum*, PHIL.; rare.
*Columbella rustica (Voluta), L.; rare.
Mitra lutescens, LAMK.; rare.
Mitra Savignyi, PAYR.; rare.
Mitra *scrobiculata*, BROCC.; very rare.
Ringicula auriculata, MENK.; very rare.
Cypræa coccinella, LAMK.; rare.
*Cypræa Pulex, SOLAND.: rare.
*Cypræa lurida, L.; very rare.
Conus mediterraneus, BRUG.; rare.
Dentalium dentale, L.; rare.
Dentalium multistriatum, DESH.; rare.
Dentalium entale, L.; rare.
Ditrupa subulata, DESH.; rare.]

† This fossil (see above, p. 779) is figured by BASTEROT, Bord. p. 31, t. 1. fig. 22, and has been described by Dr. ARADAS under the name of *Trochus Zuccarelli*.

C.

[List of Fossil Shells and Echinoderms found at Catira near Catania, by Signor Gaetano G. Gemmellaro (see above, p. 779).

N.B. *The species marked in italics are extinct, or not known as living.*

Mollusca.

Solen coarctatus, L.
Corbula gibba, Olivi.
Lutraria elliptica, Lamk.
Psammobia costulata, Turt.
Astarte incrassata, Brocc.
Venus radiata, Brocc.
Venus fasciata, Donov.
Venus exoleta, L.
Venus *vetula*, Bast.
Venus verrucosa, L.
Venus Cyrilli, Scacc.
Cardium echinatum, L.
Cardium Deshayesii, Payr.
Cardium sulcatum, Lamk.
Cardium lævigatum, L.
Cardium papillosum, Poli.
Cardita corbis, Phil.
Pectunculus pilosus, Lamk.
Pectunculus glycimeris, Lamk.
Pectunculus *minutus*, Phil.
Pectunculus *sulcatus*, Poli ?.
Nucula sulcata, Bronn.
Nucula margaritacea, Lamk.
Pecten Jacobæus, L.
Pecten opercularis, L.
Pecten polymorphus, Bronn.
Pecten aspersus, Lamk.
Pecten *palmatus* ?, Lamk.
Anomia ephippium, L.
Anomia polymorpha, Phil.
Ostrea sp., not determinable.
Ostrea, sp. not determinable.
Calyptrea vulgaris, Phil.
Natica millepunctata, Lamk.
Natica olla, M. de Serres.
Natica macilenta, Phil.
Scalaria communis, Lamk.
Scalaria tenuicosta, Michaud.
Trochus magus, L.
Trochus Adansonii, Payr.
Trochus conulus, L.
Trochus striatus, L.
Trochus lævigatus, Phil.
Turritella communis, Risso.
Cerithium lacteum, Phil.
Fusus, sp. undetermined.
Murex Brandaris, L.
Murex Trunculus, L.
Aporrhais pes-pelecani, L.
Morio thyrrenus ?, Gm. (Cassidaria).
Buccinum *semistriatum*, Brocc.
Buccinum mutabile, L.
Buccinum *striatum*, Phil.
Buccinum ascanias, Brug.
Buccinum variabile, Phil.
Conus mediterraneus, Brug.
Dentalium dentale, L.
Dentalium entale, L.
Dentalium multistriatum, Desh.
Dentalium, sp. undetermined.
Dentalium (Ditrupa) strangulatum, Desh.

Echinodermata.

Hemiaster canaliferus, D'Orb.
Brissus *cylindricus*, Agass.
Echinocyamus Tarantinus, Agass.]

XXXIII. *Note on Archdeacon* PRATT'S *Paper "On the Effect of Local Attraction in the English Arc." By Captain* A. R. CLARKE, *R.E. Communicated by Lieut.-Colonel* JAMES, *R.E.*

Received June 30,—Read November 18, 1858.

THE distances between the parallels of latitude of the principal stations of the original English Arc, as used by Archdeacon PRATT in his paper "On the Effects of Local Attraction*," are taken from the second and third volumes of the "Account of the Trigonometrical Survey." The correct distances, with the exception of that for Blenheim, are given at page 732 of the last published volume† of the Ordnance Survey. They are as follows:—

	Feet.
Dunnose and Greenwich	313716·9
Greenwich and Blenheim	132802·0
Blenheim and Arbury Hill	139837·4
Arbury Hill and Clifton	450225·2
Clifton and Burleigh Moor	406596·9

The distance, Greenwich to Bleinheim, is not altered, as there is no new determination of that quantity. The quantities λ and μ, as used by Archdeacon PRATT, do not require alteration.

The following Table exhibits the values of E and A for the several arcs:—

Arc.	Values of E.	Values of A.
1.	0·18568	·00985408
2.	0·15446	·00984849
3.	0·13546	·00987075
4.	0·09455	·00986928
5.	0·03572	·00986262

* Published in the Philosophical Transactions for 1856, Part I. p. 31.

† "Account of the Observations and Calculations of the Principal Triangulation, and of the Figure, Dimensions, and Mean Specific Gravity of the Earth as deduced therefrom." Published by Order of the Master-General and Board of Ordnance. London, 1858.

From this, taking the arcs two and two, we obtain the following results:—

Arcs compared.	Ellipticity deduced.
1st and 2nd	+0·01818
1st and 3rd	−0·03363
1st and 4th	−0·01690
1st and 5th	−0·00577
2nd and 3rd	−0·11869
2nd and 4th	−0·03516
2nd and 5th	−0·01207
3rd and 4th	+0·00364
3rd and 5th	+0·00825
4th and 5th	+0·01148
Mean value . . .	$= -0{\cdot}018067 = -\frac{1}{55{\cdot}350}$.

The value obtained by Archdeacon PRATT is . . . . . $-\frac{1}{47{\cdot}6846}$.

Taking for the elements of the mean meridian of the earth the values adopted by Archdeacon PRATT, viz.—

$$a = 20923713 \text{ feet} \quad . \quad . \quad . \quad . \quad \epsilon = \frac{1}{300{\cdot}8},$$

we obtain for the different arcs the following values of A:—

1st arc, value of A=·00986403
2nd arc, value of A=·00986301
3rd arc, value of A=·00986238
4th arc, value of A=·00986104
5th arc, value of A=·00985911

If we take the differences between these and the values before deduced, we have

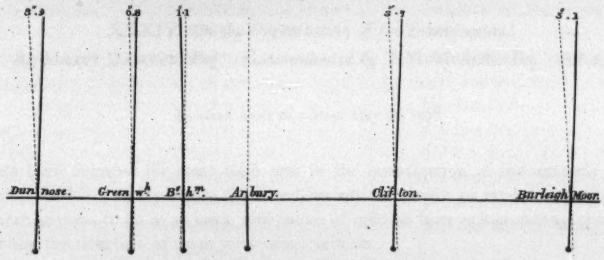
1st arc, defect of A below the mean=·00000995
2nd arc, defect of A below the mean=·00001452
3rd arc, excess of A above the mean=·00000837
4th arc, excess of A above the mean=·00000824
5th arc, excess of A above the mean=·00000351.

These quantities, multiplied by the lengths of the several arcs, give the following:—

1st arc: amplitude is in *defect* 3″·121
2nd arc: amplitude is in *defect* 1·928
3rd arc: amplitude is in *excess* 1·170
4th arc: amplitude is in *excess* 3·710
5th arc: amplitude is in *excess* 1·427

which are considerably smaller than the values obtained by Archdeacon PRATT from the data of the original work.

The diagram at page 35 of the paper referred to, will, by the substitution of the quantities just obtained, be changed to the following:



From the 'Account of the Principal Triangulation,' page 712, it appears, however, that the most probable deflections are—

At Dunnose	1″·117 South.
At Greenwich . . .	1·864 North.
At Arbury	2·226 North.
At Clifton	2·447 South.
At Burleigh Moor . .	3·589 South.

These values result from the comparison of all the geodetical and astronomical determinations in Great Britain and Ireland. When the English arc is used in the determination of the figure of the earth, in combination with the measurements in other countries, the following system of quantities is obtained (pages 764, 765):—

At Dunnose	1″·767 South.
At Greenwich . . .	1·270 North.
At Arbury	1·692 North.
At Clifton	2·864 South.
At Burleigh Moor . .	3·885 South.

From this it will be seen that the "rough approximation" of Archdeacon PRATT (at page 46 of his paper), namely, the determination of the local attraction at Burleigh Moor from the form of the masses of hill in the neighbourhood, is exceedingly near the truth. He finds 3″·660 South, which is intermediate to the quantities quoted above, viz. 3″·589 and 3″·885; but the values assigned at page 47 for the deflections at the other stations are not correctly inferred.

XXXIV. *On the Organization of the* Brachiopoda.

By ALBANY HANCOCK, *Esq.* *Communicated by* T. H. HUXLEY, *Esq.*, *F.R.S.*

Received April 24,—Read May 14, 1857.

HAVING been engaged for some time past in the investigation of the anatomy of the Brachiopods, I beg to lay before the Royal Society the results of my labours; and I am the more anxious to do so as some differences of opinion have arisen among naturalists respecting the structure of these interesting animals.

Four years ago I had occasion to dissect *Waldheimia australis*, *Terebratulina caput-serpentis* and *Lingula anatina*, and was then struck with the peculiar appearance of the organs denominated hearts by Baron CUVIER, Professor OWEN, and all subsequent writers on the subject. These so-called hearts seemed to me very unlike any molluscan heart that had ever come under my observation; and on attentive examination it became evident that they give off no arteries as they had been described to do; and moreover that their apices, from which the arteries were stated to pass, appeared to open externally. For these, and for other reasons, I was inclined to disbelieve in their cardiac nature, and to regard them rather as oviducts.

I examined at the same time, with considerable care, the alimentary tube of the *Terebratulidæ*, my attention having been particularly drawn to this matter by Mr. WOODWARD, who pointed out that the intestine appeared to him to terminate, not as described by Professor OWEN, but within the visceral chamber. I found this to be the case; and though I failed to demonstrate an anal outlet, yet was disposed to believe in the existence of a minute anal puncture, and thought the refuse of digestion might possibly make its escape by the foramen of the peduncle. However this might be, it was quite obvious that no anal aperture was situated in the pallial chamber in the two species examined. In *Lingula*, indeed, the anus was easily observed, placed at the right side, between the margins of the mantle. I also examined the muscular apparatus, and likewise the nervous system; and the complicated structure of the mantle was found to invite further investigation.

Other and more urgent matters, however, at that time claimed my attention, and all further inquiry into the structure of the Brachiopods was necessarily deferred. The results obtained were nevertheless partially made known, and have to a considerable extent been substantiated by the more recent investigations of Professor HUXLEY, who in 1854 published a very important paper on the anatomy of the Brachiopods, in the 'Proceedings of the Royal Society.' In this paper the author arrives at the conclusion that in *Waldheimia* and *Rhynchonella* there is no anus at all; but that the intestine

terminates in a blind sac within the visceral chamber; that the so-called hearts give off no arteries, and that they possibly open externally. Mr. HUXLEY also describes, for the first time, a system of ramified peripheral channels, and two or three pyriform vesicles, one of which is attached to the stomach, and is in connexion with a series of "ridges" and "bands." Some of these ridges are stated to pass from the so-called hearts to the genitalia; and the whole apparatus is regarded as forming a portion of the circulatory organs.

It is chiefly on the points thus raised by Professor HUXLEY and myself, respecting the vascular and alimentary systems, that there is a difference of opinion,—Professor OWEN maintaining the generally received belief in the existence of an anal aperture situated in the pallial chamber in the *Terebratulidæ*, as well as in *Lingula*; and that the so-called hearts are true vascular centres propelling the blood through arteries to the various organs.

Such being the case, a thorough investigation of the facts had become necessary. I have therefore applied myself most diligently and earnestly to the subject, fully impressed with a sense of the weight of authority opposed to the views I entertain in common with Professor HUXLEY, and with the most anxious desire to establish the truth, as it is of some importance that the anatomy and physiology of these, apparently, much misunderstood animals should be accurately determined.

In a short communication which I made to the Meeting of the British Association held at Cheltenham last year[1], the results up to that time were specified, as far as they related to the matters in dispute. On the present occasion, however, I shall not confine myself to these points; but purpose giving in the following pages, as far as possible, full and complete details of the entire anatomy of such of the Brachiopods as have come under my observation. And here it must be stated that I should never have been able to enter upon this subject, with any chance of success, had I not had at my command an ample supply of specimens, and that I am indebted for this great advantage to the liberality of Dr. GRAY, Mr. WOODWARD, Mr. DAVIDSON, Mr. HUXLEY, Mr. MCANDREW, Mr. ALDER, and Mr. LECKENBY. My best thanks are therefore due to these gentlemen for having placed at my disposal specimens of the following species:—*Waldheimia australis*, *W. cranium*, *Terebratulina caput-serpentis*, *Rhynchonella psittacea*, *Lingula anatina* and *L. affinis*[2]. These are the only forms that I have dissected, though I have enjoyed the opportunity of seeing the animal, in a more or less perfect state, of one or two other species, to which allusion will, occasionally, be made in the following pages.

The shells of the Brachiopods are now so well known that it would seem quite unnecessary to give here any detailed account of them. But it may perhaps be as well to observe that they are formed upon two distinct plans, one having the valves articulated, the other having them unarticulated. *Waldheimia* is a type of the former, *Lingula* of the latter. Those with articulated valves have the hinge generally furnished with teeth and corresponding sockets, which so lock the valves together, that their action is very

[1] Report of the British Association for 1856; Transactions of the Sections, p. 94. [2] Note 1, p. 850.

limited, and that on separating them fracture ensues. In the unarticulated forms the valves do not move upon each other, for when open no part of their margins are in contact; there is no hinge, properly so called, and like the former group their gape is extremely limited; at least such is the case in *Crania*, which has been observed in a living state.

The two divisions of the Brachiopods thus indicated, at the outset of our inquiry, will be found, as we proceed, still more strongly marked by their internal organization.

The valves, as generally acknowledged, are placed on the dorsal and ventral surfaces of the animal; the imperforate being the dorsal, the perforate the ventral valve in the *Terebratulidæ* and their immediate allies[1]. Thus that side which is *below* when the animal is attached by its peduncle is really the back. If this were ever doubted, the discovery of the true heart, as we shall afterwards see, confirms the accuracy of Professor OWEN's determination of these points. In *Lingula*, the large valve, or that to which the peduncle is attached, corresponds to the perforate or ventral valve of the *Terebratulidæ*, the small one to the dorsal.

To facilitate the examination of the soft parts, it is necessary to reduce the valves by dissolving them in dilute acid. When the calcareous matter has entirely disappeared, and the decalcified shell-membrane has been removed, the transparent tegumentary envelope of the animal is exposed to view; and this, when placed in water, assumes the form of the shell[2]. The pallial lobes extend forward, but do not project beyond the sides of the body, where they become united, the junction being marked by a groove, bordered by a ridge on each side. They are very delicate and transparent, so that the great pallial sinuses can be distinctly traced, even to their terminal ramifications; and the genitalia, which lie within them, appear through their walls of a full yellow colour. Towards the posterior or umbonal region the enlarged extremities of the shell-muscles are always apparent, clustered together, on each side of the antero-posterior line, forming reddish flesh-coloured patches. On the dorsal surface the liver is seen occupying the space between the muscles, and on the ventral, the termination of the intestine makes its appearance as a minute, circular point, immediately behind the central or occlusor muscles in *Waldheimia australis*. In *Rhynchonella* it is seen in the same position enlarged, rounded and doubled upon itself[3].

On turning the pallial lobes back, the arms[4] are found to occupy almost the entire pallial cavity, which is very extensive, reaching backwards for two-thirds the length of the shell; the posterior third being filled up with the body of the animal. The mouth opens upwards, on the median line, in the brachial groove; and on each side of it, a little below, in the anterior wall of the body, there is an opening which leads into the abdominal cavity or perivisceral chamber. These orifices are situated at the apices of the two elongated organs designated hearts by Professor OWEN[5]. These so-called hearts

[1] Note 2, p. 851.

[2] Plates LII. and LIII. figs. 1, 2.

[3] Plate LX. fig. 2.

[4] Plate LV. figs. 1, 2.

[5] Introduction to Mr. DAVIDSON's 'British Fossil Brachiopoda,' published by the Palæontographical Society, p. 14, 1853.

are partially buried in the parietal membrane, and are generally seen shining through of a yellow colour.

No anal aperture can be detected in any of the articulated Brachiopods that have come under my observation, either at the point where the intestinal tube terminates or within the pallial cavity, or anywhere else. Thus it would appear that in this group there are three external orifices, two being at the apices of the pseudo-hearts, the third is the mouth. In *Rhynchonella*[1], however, there are five openings, this genus having four of the so-called hearts or oviducts, two of which are situated as in the *Terebratulidæ*, and two above the mouth, one being at each side of the liver.

In *Lingula*[2] the body of the animal is depressed, and occupies a much larger portion of the shell-cavity than it does in either the *Terebratulidæ* or *Rhynchonellidæ*. The pallial lobes are rather stout; but the great sinuses are nevertheless distinctly seen through their membranes; they are not united behind, as in the articulated Brachiopods, but are free and extend some distance from the body all round the posterior or umbonal region. The body thus becomes well defined, the lateral walls being at right angles to the dorsal and ventral. The two latter are very delicate, and so transparent that the viscera are quite apparent through them, the liver and genitalia being the most conspicuous. The lateral parietes are strong and muscular, and, having their edges attached to the valves, give a definite form to the enclosed space, which is wide, rounded in front and tapering backwards.

On turning back the ventral pallial lobe[3] the arms are observed occupying the greater portion of the pallial chamber, which is about half the length of the shell. The mouth is situated, as in the *Terebratulidæ*, in the brachial groove; and on each side of it, a little below, are the ovarian outlets, which penetrate the anterior wall of the body. On the right side of the animal, between the margins of the mantle, is placed the anal orifice, which is very distinct and easily detected.

The best view of the viscera is obtained, in the articulated forms, by laying open the dorsal wall of the body, along the central line, from the umbo to the anterior wall. In this way all the organs[4] are seen in their natural positions, lying within the perivisceral chamber. The alimentary tube is observed extending from the front to the posterior extremity of the chamber, the anterior portion, the stomach, being somewhat enlarged, and partially concealed beneath the two lateral divisions of the folliculated liver. The true heart, in the form of a rather large, pyriform vesicle, is appended to the dorsal surface of the stomach; and on each side of the chamber, above and below, is an accessory pulsatile vesicle. A little behind the heart, at the sides, are the oviducts, two large funnel-shaped organs with laminated interiors,—the hearts of Professor Owen. The four genital organs are placed at the sides, above and below, protruding, from the great pallial sinuses, into the perivisceral chamber; and the various muscles are seen arranged at each side of the alimentary tube stretching from wall to wall.

[1] Plates LV. fig. 3; LX. fig. 3.

[2] Plates LXIV. figs. 1, 2; LXVI. figs. 1, 3.

[3] Plates LXIV. fig. 3; LXVI. fig. 2.

[4] Plates LII. fig. 10; LIII. fig. 5; LIV. figs. 1, 2.

On removing the dorsal parietes in *Lingula*[1], the alimentary tube is found to occupy a central position as in the articulated tribes, the anterior portion being buried, as in them, beneath the lobulated liver, which is rather bulky. On displacing the latter, the heart is seen attached to the upper surface of the stomach, and the two dorsal genital organs are entirely exposed, extending nearly the whole length of the perivisceral chamber. At the sides and in front of these are the extremities of the muscles, and behind are the convolutions of the intestine. The pseudo- or Cuvierian hearts are hidden below the genitalia and muscles.

Having taken this general survey of the external and internal parts, we shall now examine, in detail, the various systems of organs, beginning with that of the muscles.

Muscular System.

In the Brachiopods the muscular system is very complicated and peculiar in its arrangement. Five or six pairs of muscles have been described in the *Terebratulidæ*, all of which have relation to the movements of the valves upon each other, or to their attachment to, or movements upon the peduncle. Thus the muscles naturally divide themselves into two groups,—the valvular, and those for adjusting the shell to the peduncle. Of the former there are three pairs, which have been denominated respectively adductors, cardinals and accessory cardinals; of the latter there are likewise three pairs, which have deen designated the dorsal pedicle muscles, the ventral pedicle muscles, and the capsular muscles. The capsulars, however, are generally blended into one, and in this state they have been named "capsularis" by Professor Owen[2].

Before entering upon the description of these several pairs of muscles, it is necessary to say a word or two on the names they have received, which do not appear satisfactory. The epithets cardinal and accessory cardinal given to two of the pairs of valvular muscles are objectionable, for they would seem to imply that these muscles presided exclusively over the movements of the hinge, or that they are exclusively the muscles of the hinge. They open the valves, the adductors close them. In this sense these, as well as the others, might be called cardinal muscles, all being equally related to the hinge; but surely it is improper so to name the first-mentioned muscles, and not the last. And as to the attachment of the first-mentioned to the cardinal process, this should not entitle them to be called cardinals any more than the dorsal pedicle muscles, which, being inserted into the hinge-plate, in most instances, would seem thereby to have equal claim to the title. These epithets will therefore be discarded, and those of divaricator and accessory divaricator substituted. The adductor muscles will be named the occlusors, the present denomination not being sufficiently precise.

With regard to the pedicle muscles, these, as will be afterwards shown, having the office of adjusting the shell to the peduncle, will receive the name of adjustor muscles. This alteration is also rendered necessary because the capsular is really the peduncular muscle, and will be so denominated.

[1] Plates LXIV. fig. 4; LXV. fig. 3; LXVI. fig. 1.

[2] Introduction to Davidson's 'British Fossil Brachiopoda,' p. 8.

In *Waldheimia australis*[1] the occlusors have their inferior or ventral terminations placed close together, forming an elongated oval mass, which is attached to the valve about one-third the length of the shell from the beak or perforate extremity on the median line. From this point they pass diagonally upwards and forwards towards the imperforate or dorsal valve, continuing united for some distance; they then separate, and diverging laterally, become much attenuated and assume the form of tendons. Up to this point they are firmly attached to the anterior wall of the body, but beyond it become perfectly free. Each muscle then almost immediately divides into an anterior and posterior portion, which run parallel to each other, on either side of the alimentary tube and liver, and on reaching the dorsal valve are each attached to it by a distinct, much enlarged extremity, at a little distance from the median line. These two divisions of the occlusor muscles have been denominated by Professor OWEN "adductor longus anticus," and "adductor longus posticus" respectively[2], and in this paper will receive the distinctive appellations of anterior and posterior occlusors. The former is considerably the stouter, and the enlarged attachment of both are seen close together at the surface of the body after the shell has been removed; they are of a pyriform contour, the pointed end of the anterior and larger being inclined inwards and backwards, that of the posterior in the opposite direction. All the four dorsal extremities are of a reddish flesh-colour, resembling muscle; but with this exception, the muscles are throughout dense, glistening and tendon-like, even including the enlarged ventral extremities. These muscles are undoubtedly for the purpose of closing the valves.

The divaricator muscles arise from the ventral valve, one on each side, a little in advance of, and close to the united bases of the occlusors. These extremities are large, fleshy, and of a reddish-yellow colour; they rapidly diminish in size, and attain the appearance of white, glistening tendons; and, having the intestine between them, converge as they pass backwards and upwards towards the cardinal process, into which their superior, attenuated extremities are inserted in close contiguity.

The accessory divaricators are a pair of small muscles which have their enlarged carneous ends attached to the ventral valve on each side of the median line, a little behind the united bases of the occlusors, and the termination of the intestine is seen immediately in front of them. At the surface of the body they appear as two oval reddish discs, and they become, almost at once, reduced into flattened tendons, which, running parallel to each other, incline upwards and forwards, course round the inner extremity of the peduncular capsule, to the upper surface of which they become firmly united, and as they advance blend some of their fibres with those of the divaricators, and go thus united with them to be inserted into the extreme point of the cardinal process.

The function of these two pairs of muscles is obvious enough; it is to open or divaricate the valves. The cardinal process projecting backwards beyond the hinge or fulcrum formed by the teeth and sockets, when these muscles contract the process will be drawn inwards, and consequently the anterior margins of the valves separated, the action being that of a lever of the first order. This peculiar mode of opening the valves

[1] Plates LII. figs. 2, 10; LIV. fig. 1; LVII. figs. 1, 2; LXII. fig. 1.

[2] *Op. cit.* p. 8.

appears to have been first pointed out by Professor QUENSTEDT[1]; and this characteristic feature of the articulated Brachiopods was commented upon and fully appreciated by its discoverer.

Though this is undoubtedly the primary function of the two pairs of divaricators, yet as they are intimately united to the capsule of the peduncle, when in action they will likewise pull it downwards towards the ventral valve, thus giving room for the cardinal process to pass inwards, which it must always do when these muscles are in action. And moreover, from the position of the ventral attachment of the accessory divaricators, and from their coursing round the base of the peduncular capsule to their superior attachment, it is evident that whenever exerted they will have a tendency to thrust out the peduncle. Thus the opening of the valves must always be accompanied by an elevation of the animal upon its support, though this can never be to any great extent.

The peduncle, being the medium by which the Brachiopod becomes attached to foreign bodies, is the fixed point upon which the limited movements of the shell are effected; and the adjustor muscles, having one of their extremities attached to this organ, may be considered as taking their origin in it. It will therefore be well, before describing them, to examine the structure of the peduncle itself. This organ[2] is composed of a dense muscular or semi-cartilaginous mass of a cylindrical form, with one extremity exserted through the foramen of the ventral valve, and the other resting within its umbonal region. The protruded extremity is protected by a thick, horn-like covering of a brownish colour; it is short and stout, possessing little or no elasticity, and has a fibrous expanded base of attachment. The inner extremity is enlarged, and is received into a capsule, which is formed by the invagination of the tegumentary envelope at the margin of the foramen. The peduncle is attached to the bottom of this capsule, through which it sends a wide, narrow belt of muscular fibres, to be inserted into the valve immediately behind the accessory divaricators. This muscle is short and white, like the muscular portion of the peduncle, and appears at the surface of the tegumentary envelope as a narrow, transverse, pale patch, extending almost across the umbonal region. This is, as previously stated, the "capsularis" muscle of Professor OWEN. Its function, however, is not merely to attach the capsule, but is in an especial sense to unite the peduncle to the shell, as proved by the homologous muscle in *Lingula*, and by the direction of its fibres, which are the continuation of those forming the core of the peduncle, or more properly the peduncle itself, running from one end of the organ to the other. When in action, it will have the effect of erecting the shell and steadying it upon the peduncle.

The movements of the shell, however, upon this support, will be chiefly effected by the action of the adjustors, of which we have seen there are two pairs, the dorsal and

[1] "Ueber das Œffnen und Schliessen der Brachiopoden," WIEGMANN'S Archiv, vol. ii. pp. 220–222, pl. 4. figs. 4, 5, 6, 1835.

[2] Plate LVII. figs. 2, 3, 4.

ventral. The former of these are attached to the ventral surface of the peduncle, forming a dense mass by the intermingling of their fibres; they pass, one from each side of the peduncle near its inner extremity and just above the origin of the peduncular muscle, through the capsule forwards and upwards, diverging a little and having the divaricators between them, to be inserted into the hinge-plate, one on each side, a little in advance of the cardial process. At the point of insertion each seems as if formed of two portions. These muscles, throughout their whole length, are yellowish, fibrous and fleshy, and not much enlarged at their insertions.

The ventral adjustors pass from the inner extremity of the peduncle, and penetrate the capsule on each side, a little above the dorsal pair; they originate in a firm mass cemented to the dorsal surface of the peduncle, very similar to that which connects the other pair to this organ: the two masses give a bulbous form to the inner extremity of the peduncle. At first the muscles are delicate and tendinous; but coursing downwards and forwards they rapidly enlarge and become attached to the ventral valve, one on each side of, and a little behind, the expanded base of the divaricators. They form the external pair of muscular discs seen, when the shell is removed, clustered together towards the umbonal region of the ventral surface. These discs are of a reddish colour, and in size and shape resemble those of the divaricators, being of an irregular oval form.

The two pairs of adjustor muscles are evidently for the purpose of moving the shell upon the peduncle, and to some extent are antagonistic to each other. When the dorsal pair are contracted and the ventral relaxed, the shell will be depressed, and they elevate it on this action of the two muscles being reversed. But their chief function would appear to be, to rotate the shell from side to side; this will be effected by the right and left muscles of each pair alternately contracting and relaxing. The shell will be firmly fixed and the peduncle withdrawn to the fullest extent, when both these pairs and the peduncular muscle are in a state of contraction.

The arrangement of the muscles is essentially the same in all the articulated Brachiopods that have come under my observation. There are, however, one or two rather interesting modifications of detail, even in the *Terebratulidæ*, which require particular notice. The first of these occurs in a species so like *W. australis*, that I took it, at first, to belong to that form, but am now inclined to think that it must be distinct from it[1]. In this[2] the divaricators and their accessories are united so as to form only a single pair, the attachment of the muscle to the ventral valve extending all the way from the peduncular muscle to considerably in advance of the occlusors. The connecting portion, however, is much attenuated, forming as it were a narrow neck of communication between

[1] It appears that more than one species is included under the name of *Australis*. The specimen above alluded to was very large and fine, with the anterior margins of the valves much and suddenly bent inwards, and the ribs few and very large; it resembled figs. 25 and 28, plate 69, of the 'Thesaurus Conchyliorum' of Sowerby.

[2] Plates LII. fig. 3; LIV. fig. 1; LXII. fig. 4.

the two, when the muscle is exposed at the surface of the body; thus seen, the extremity has somewhat the shape of a battledoor; and the pair meeting behind almost entirely enclose the occlusors and the terminal extremity of the intestine. Though thus altered and combined into one, the function of this single pair of muscles will be exactly the same as when divided into two, as the areas of attachment are not materially changed. It will, in fact, open the valves and at the same time protrude the peduncle; but on account of the combination, the two actions may perhaps be rendered more harmonious, and probably somewhat invigorated.

Another and more important modification obtains in *W. cranium* and *T. caput-serpentis*[1]. In these two species the dorsal adjustor muscles are not attached to a hinge-plate, as in *W. Australis*, but have their insertions in the valve itself, and are very large and powerful. In both species the superior extremities of these muscles are seen at the surface of the animal, on each side of the median line, elongated in the antero-posterior direction, and extending between the occlusors almost as far forward as their anterior margins. They are enlarged posteriorly, particularly in *T. caput-serpentis*, in which they are of an irregular form.

The divaricators and the accessory divaricators in *W. cranium*[2] are likewise united in the same manner as in the species before alluded to.

The modification of the dorsal adjustor muscles cannot be of much importance in a physiological point of view; it will, however, increase their power in proportion as the area of their insertions is extended. Moreover, these muscles are largely developed as well as the ventral pair. It would therefore seem probable that the movements of the shell upon the peduncle, in these species, may be more extensive and livelier than usual. But to the palæontologist, to whom the muscular impressions in fossils are of great value, these modifications cannot fail to possess considerable interest, evincing as they do to what extent the arrangement of the muscles may be modified without any essential change in the economy of the animal. In the dorsal valve there may be, as in the above examples, as many as six muscular impressions instead of four, and in the ventral there may be two less than usual; facts sufficiently puzzling without the light of anatomical investigation. It is also worthy of remark, that in those species with the dorsal adjustor muscles attached to the valve there is no hinge-plate[3]; and therefore it may be presumed that in the fossil species with this plate deficient the muscles will be arranged in the same manner.

In *Rhynchonella psittacea*[4] the general disposition of the muscles is the same as in *W. australis*, only they are longer and more slender, particularly the occlusors, which, with the exception of their extremities, are thin and tendinous. The surfaces of attachment also vary a little in form, as can be readily seen on removing the shell. The extremities of the muscles are then observed, as usual, at the ventral surface of the animal, clustered together, a little in advance of the umbonal region. The occlusors are almost

[1] Plates LIII. figs. 1, 3, 5; LXII. fig. 2.
[2] Plate LIII. fig. 4.
[3] Plate LII. fig. 5.
[4] Plates LX. figs. 1, 2; LXI. figs. 1, 2.

colourless, narrow and elongated, and have their anterior margins united on the median line; posteriorly they diverge, leaving a space between them, in which the terminal extremity of the intestine is seen. The divaricators are very large, and are placed external to, and in contact with, the occlusors; they are broad and fan-like in front, exhibiting radiating divisions, and meet on the median line, in advance of the occlusors. Behind they are produced and pointed. The ventral adjustor muscles have their extremities narrow and much elongated; they rest against the external margin of the divaricators, are enlarged a little, and converge posteriorly. Unlike *Waldheimia*, there is here *a pair* of peduncular muscles seen at the sides of the umbo, having between them the accessory divaricators, which are of a somewhat triangular form. The dorsal terminations of the occlusors present nothing remarkable in their appearance. All the extremities of the muscles seen at the surface of the animal are of a yellowish-red colour, except those of the peduncular muscles and the ventral terminations of the occlusors.

In the unarticulated Brachiopods, taking *Lingula*[1] as the type, the muscles are exceedingly complex in their arrangement, even more so than in those already examined. In all six pairs have been described, the whole of which, having both extremities attached to the valves, might be denominated valvular muscles; but only a portion of them can be looked upon as the equivalents of those so attached in *Waldheimia*. They have been divided by previous writers into adductors and sliding muscles, the latter being again subdivided into protractors and retractors.

It is necessary to alter these latter epithets, as they imply what appears to be a false theory, namely, the sliding of the valves over each other; and as it is desirable to make still further changes in the nomenclature, the names that the muscles have already received are placed below, with those now proposed for adoption. The names of the homologous muscles of the articulated Brachiopods are appended, so that the relation of these organs in the two groups may be seen at a glance.

Names in use.	Names proposed.	Names of homologous muscles of articulate Brachiopoda.
Anterior retractors . . .	Anterior occlusors . .	Anterior occlusors.
Anterior adductors . . .	Posterior occlusors . .	Posterior occlusors.
Posterior adductors. . .	Divaricators	Accessory divaricators.
Central protractors . . .	Central adjustors . . .	Ventral adjustors.
External protractors . .	External adjustors . .	
Posterior retractors. . .	Posterior adjustors . .	Dorsal adjustors.
Capsular	Peduncular	Peduncular.
	Anterior parietals.	
	Posterior parietals.	

The anterior occlusors are a pair of stout muscles, of about equal thickness throughout; they pass from the ventral valve, one at each side, in front of the visceral mass, close to the lateral walls of the body, and a little behind the transverse centre of the

[1] Plates LXII. fig. 3; LXIV. figs. 4, 5; LXV. figs. 2, 3.

shell; inclining forwards and inwards, they go to be attached to the sides of the central ridge of the dorsal valve, about one-third the length of the shell from the anterior margin. The dorsal extremities are compressed, and have their sides in contact.

The posterior occlusors are rather stouter and much shorter than the anterior pair, and go directly from valve to valve, parallel to each other, one a little on each side of the longitudinal central line. They run internal to the anterior occlusors, and are just sufficiently apart from each other to allow the passage of the alimentary tube, which rises up between the anterior pair. The ventral extremities of the posterior occlusors are placed a little in advance of the corresponding terminations of the anterior pair, and the dorsal extremities of the former are situated a little behind those of the latter. The dorsal ends of the posterior occlusors are partially encircled by the gastro-parietal bands.

These two pairs of muscles are mainly instrumental in closing the valves, and there can be little doubt that they homologically represent the occlusors of the articulated Brachiopods. There are here, however, four distinct muscles; in *Waldheimia* we have seen that the two pairs are blended at their ventral extremities. Both pairs in *Lingula* are attached to a transverse fold of the anterior wall of the body, which is also the case with the occlusors in the articulated species; and in them, and in *Lingula*, the œsophagus is similarly related to these muscles. In the latter species the anterior occlusors are inclined, and in this respect resemble the closing muscles of the *Terebratulidæ*, and particularly the anterior pair, which are the more inclined of the two. The posterior occlusors are peculiar in going direct from valve to valve; but that they are the homologues of the so-named muscles in *Waldheimia*, appears proved by their relation to the gastro-parietal bands, which is the same in both cases.

The divaricator, though forming a single mass, is really two muscles combined. It is stout and short, and is situated at the posterior extremity of the perivisceral chamber, passing directly between the valves, and having its attachments immediately within the umbones: the extremities have a semicircular form, arched behind and slightly bifid in front, indicating its double nature. This muscle is perhaps the equivalent of the divaricators in *Waldheimia*, though it seems more likely that it homologically represents only the accessory divaricators, which in position exactly agree with it. And that portion of the intestine which corresponds to the intestine in the *Terebratulidæ*, terminates in front of it, at the ventral wall of the body, just as the intestine does in them.

The action of the divaricator is to approximate the umbonal regions, and thus, pressing forward the fluid in the perivisceral chamber, to open the valves in front. Other muscles are, however, likewise employed to assist in this office. The lateral walls[1] of the body are thick and strong, being amply supplied with transverse muscular fibres which pass from one valve to the other. The fibres are strongly developed towards the posterior extremity of the chamber, where they form a thick inner layer. These may be denominated the posterior parietal muscles. The walls of the anterior recess of the

[1] Plate LXVI. figs. 1, 3, 4.

perivisceral chamber are also well supplied with fibres. In front a powerful muscular band, in connexion with the parietes, extends along each side, above the oviducts, from the anterior wall of the chamber to behind the dorsal extremities of the adjustors: these are the anterior parietals. As the walls, with which these two sets of muscles are connected, arch outwards when they are relaxed, it is evident that when in action they will straighten the curvature, and thus diminish the capacity of the perivisceral chamber. The posterior parietals will also assist in drawing together the umbonal regions of the valves. Now when the divaricator muscle contracts and the anterior occlusors relax, the fluid contained in this chamber will be pressed forward; the anterior parietals then coming into play compress the space in front, and the lateral walls behind losing their curvature and becoming firm and resistent, from the action of the posterior parietals, the valves will be constrained to open anteriorly. This, there can be little doubt, is the mechanism employed in opening the valves in *Lingula*; and it is probably the same in all the unarticulated Brachiopods: we know that in *Crania* and *Discina* the muscles are arranged after the same plan, and the muscular impressions in the fossil species would seem to indicate that in them also they were similarly disposed.

The pair of central adjustors are attached to the ventral valve, by fine points, between the posterior occlusors in front; they are placed close together, one on each side of the median line: sweeping round the inner border of these muscles they diverge posteriorly, and, increasing in size as they go, ascend towards the dorsal valve, to which they become adherent, one at each side immediately within the parietes of the body.

The external adjustors arise from the ventral valve, at the outside of the posterior occlusors, and in contact with them; they are at first pretty stout, but on passing outwards and backwards they enlarge a little, and ascending are inserted into the dorsal valve, one on each side immediately behind the central pair.

The posterior adjustors are large and powerful muscles, and though they may be considered as a pair, they are asymmetrical, there being two on one side, and only one on the other. As they pass across from valve to valve they intersect each other, the single one passing between the other two. These are the decussating muscles of authors. The single one is as large as the other two put together, and is attached to the left side of the ventral valve about midway between the divaricator and the anterior occlusor. From this point it passes diagonally upwards and forwards between the reproductive organs, having the alimentary canal above it; and on reaching the opposite side of the dorsal valve, has the other end inserted into the latter, immediately within the posterior terminations of the external and central adjustors of the same side. At the points of attachment the three muscles are pressed so close together, that they appear, at first sight, as only one.

The two opposite posterior adjustors take their origin from the right side of the ventral valve, considerably apart; but both of them close to the lateral parietes of the body, one only a little in advance of the divaricator, and the other a short distance further forward. They converge as they penetrate the visceral mass, and, sloping

forward, one on each side of the single muscle, with the alimentary tube above them, they ascend to their insertion into the left side of the dorsal valve directly within those of the external and central adjustors. Therefore, at this point, there are the terminations of four muscles in close contact.

The three pairs of adjustors are apparently for the purpose of keeping the valves opposed to each other,—of holding them adjusted; and in this respect they seem well calculated to compensate for the deficiency of a hinge and condyles, which are entirely wanting in *Lingula*. The external and central pairs having their anterior extremities attached to the ventral valve (which as it is fixed to the peduncle is that from which all the muscles act) and their posterior ends to the dorsal, it is evident that they will prevent the latter from being forced backwards; while the posterior adjustors having their posterior terminations united to the ventral or fixed valve, and their anterior to the dorsal, they will act in the contrary direction and guard against any pressure forward. They will also at the same time prevent any lateral displacement of the valves, as their diagonal position will enable them to act transversely as well as longitudinally. And the external and central adjustors will, on account of their oblique arrangement, likewise exert a similar double influence in front.

Indeed the attachments of the various muscles are so distributed around the margin of the perivisceral chamber, that transverse, longitudinal and diagonal movements are alike guarded against. And perhaps their true functions are best understood when thus considered in co-operation; it is then seen that they form a complicated complementary system for the purpose of assisting in adducting the valves, their various points of attachment and different inclinations being so arranged, that, in whatever state of action they may happen to be, they will always keep the valves steadily and accurately opposed to each other. When all these muscles are contracted, and the occlusors and divaricators co-operate, the valves will be forcibly held together and capable of resisting considerable violence.

The adjustor muscles have had, however, a very different office assigned to them by Cuvier[1] and Owen[2], and by all subsequent writers on the subject, who have denominated them sliding muscles, believing that they were for the purpose of moving the valves over each other, and thus opening them. And it must be admitted that they would seem capable of performing the function attributed to them by these distinguished physiologists. But it may be asked, where is the necessity, and what is the probability of the existence of any such sliding motion? In the Lamellibranchs nature seems to have exhausted her ingenuity in a variety of plans to prevent the sliding of the valves; and in the articulated Brachiopods we find extraordinary means adopted to attain the same end. In the latter, the valves are not only not permitted to move over each other, but the teeth of one are so locked into the sockets of the other that their gape is exceedingly limited,

[1] "Mémoire sur l'animal de la Lingule," Mémoires pour servir à l'histoire et à l'anatomie des Mollusques, 1817.

[2] Lectures on Comparative Anatomy, 2nd ed. p. 489, 1855.

as if it were necessary to avoid disturbing the internal parts by a too extensive action even in this direction.

Now, the organization of *Lingula* is so similar to that of the *Terebratulidæ* as to make it difficult of belief that all this precaution, to prevent the displacement of the valves, should be necessary in the one case, and that in the other a special apparatus should be provided to bring it about. As *Lingula* is deprived of a hinge, teeth, and sockets, should we not rather expect to find some especial means provided to compensate for such important deficiencies? And do we not see in the large development and complicated arrangement of these muscles such compensation? This can hardly be doubted; and in corroboration of this opinion it may be stated, that Mr. BARRETT, who has had the opportunity of observing *Crania* alive, states that it opens the valves "by moving upon the straight side as on a hinge without sliding the valve[1]." This would seem almost conclusive.

The homologues of the adjustor muscles cannot be determined with any great degree of confidence, though it would seem probable that they represent the muscles so named in the articulated Brachiopods. From their posterior position this might perhaps be inferred, and the relation of the ventral terminations of the external adjustors to those of the posterior occlusors, is very similar to the relation of the ventral adjustors to the terminations of the occlusors in *Waldheimia*. It would therefore seem likely that the external and central adjustors are the equivalents of the ventral adjustors of that genus. It does not signify much that in *Lingula* these muscles are divided into two pairs; for we have seen in *Waldheimia* the liability of the muscles to become double. If this determination be correct, then the posterior occlusors will be homologous with the dorsal adjustors of the articulated group. Mr. WOODWARD states, in his excellent Manual[2], that some of these muscles in *Discina* are probably inserted into the peduncle, and if so the likelihood of this view of their homology would be greatly enhanced. It is therefore most desirable that the muscular system of this genus should be fully investigated.

Before describing the peduncular muscle it is necessary to examine the peduncle itself. This is enormously developed; in one of the specimens dissected it was upwards of 9½ inches long; it is stout at the upper extremity[3], but suddenly contracts at its junction with the valve; below it tapers considerably. On making a transverse section[4], it is found to be cylindrical and a little flattened, with the walls formed of two thick concentric layers, as described by Dr. C. VOGT in his paper on the Anatomy of *Lingula*[5]. The external layer is homogeneous, semi-pellucid, yellowish, and horn-like; the inner is opake, of a yellow colour, and is composed of longitudinal muscular fibres. This muscular cylinder extends from end to end, and is rather abruptly constricted as it approaches the ventral valve and is transformed into the peduncular muscle; the central channel appears to be continued through the muscle, and is brought into communication

[1] Ann. and Mag. of Nat. Hist. vol. xvi. p. 257, 1855.
[2] Manual of the Mollusca, p. 237, 1854.
[3] Plates LXVI. figs. 6, 7; LXII. fig. 3.
[4] Plate LXII. fig. 10.
[5] "Anatomie de la *Lingula anatina*," Nouv. Mém. Soc. Helv. vol. vii. Neuchâtel, 1845, 4to. plates 1 and 2.

with the perivisceral chamber by a narrow passage which turns round the right side of the divaricator muscle. But as the peduncle had been detached before the specimen came into my possession, I cannot speak with certainty as to these points.

The peduncular muscle itself is rather small and short, and is transversely elongated; it is formed by a continuation of the fibres of the muscular cylinder, and has its insertion immediately within the umbo of the ventral valve and close behind the divaricator; thus in position it exactly resembles the same muscle in the *Terebratulidæ*, and originates in precisely the same manner.

The wall of the peduncle is united to the external surface of the pallial expansion at the umbonal region; and just within the margin, a slight fold[1], which is a little wider than the peduncular muscle, indicates a rudimentary capsule. This organ would at once be formed if the mantle were invaginated at the fold, the peduncle thrust a little inwards, and the attachment of its muscle advanced. In this case the divaricator would also have to be pushed forward, and the adjustors becoming confounded with the peduncle and its capsule, the muscles of *Lingula* would, to a great extent, assume the arrangement of those of the *Terebratulidæ*.

The brachial and pallial muscles still claim attention; but these will be more conveniently described when we come to speak of those parts.

The muscles in the *Terebratulidæ* and *Rhynchonellidæ* are peculiar for their enlarged, fleshy extremities, and for the attenuated, tendinous character of their intermediate portions[2]. The extremities[3] are mostly of a yellow flesh-colour, and are comparatively soft, with the fibres arranged in separate radiating bundles; so that a needle may be passed between them almost as far as the centre of the muscle. The tendinous portions are dense, white, glistening, firm and rigid, and are permeated with blood channels, the larger of which run in the direction of the length of the muscle. On making a transverse section of the occlusors in *W. australis*, several such channels are observed; some of considerable size, with others branching in various directions containing blood-corpuscles. Amidst the fibres of the enlarged extremities similar corpuscles are strewed about. The fibres easily separate from each other; they are cylindrical, homogeneous, transparent and devoid of cross striæ[4], with the exception of those of the posterior occlusors, in which transverse striations[5] are vividly displayed, and give to them a very striking appearance. The fibres[6] are generally formed of three, four or more fibrillæ; but single fibrillæ are frequently observed perfectly isolated, in which the cell-like structure is beautifully distinct. It will afterwards be seen that these muscles, with cross striæ, are richly supplied with nervous filaments.

The muscles in *Lingula*[7] are fleshy and of equal thickness throughout, with the single exception of the central adjustors, which taper to their ventral attachments. The bundles of fibres, though very distinct, are not separated as in the *Terebratulidæ*, and in no instance did the fibres display transverse striæ.

[1] Plate LXVI. fig. 2.
[2] Plates LVII. figs. 1, 2; LXI. figs. 1, 2.
[3] Plate LXII. figs. 4, 5, 14, 15.
[4] Plate LXII. figs. 8, 9.
[5] Plate LXII. fig. 6.
[6] Plate LXII. fig. 7.
[7] Plate LXV. figs. 2, 3.

Alimentary System.

It will be convenient to commence the description of the digestive apparatus with that of the brachial appendages,—those beautiful and complicated organs so characteristic of the *Brachiopoda*,—not from any conviction that they are essentially portions of this apparatus, but from their connexion with the sustentation of the animal, and from their position at the commencement of the alimentary tube, it seems the natural course to pursue.

These organs are variously modified in the different families, and in the *Terebratulidæ* are supported upon a calcareous loop, in connexion with the dorsal valve, more or less developed in the different species. In *Waldheimia* this loop[1] originates in the hinge-plate in two necks or processes,—the crura, from which two points project downwards, called the crural processes. The upper or dorsal members of the loop, passing from these two lateral necks, stretch forward for about two-thirds the length of the valve, then bend towards the ventral valve, and turning back upon their course, are united across the median line a short way in advance of the crural processes. The lateral portions of the loop are curved a little outwards. The whole of this calcareous support, including the crura and crural processes, is a product of the inner lamina of the dorsal pallial lobe. This lamina, with the exception of a portion at each side, which is continuous with the similar lamina of the ventral lobe, forming with it the anterior wall of the perivisceral chamber, is turned downwards and forwards, and extends as far as the transverse portion of the loop. It then divides into two lobules, one passing to the anterior extremity of each of the lateral portions of this calcareous support, binding together the dorsal and ventral members. The loop in its sinuous course follows the margins of this bifurcated pallial process, and lies imbedded in its substance.

The arms[2] themselves taper to fine points, having taken their origin at each side of the mouth, which is situated at the back of the pallial chamber in a central position, opening downwards. They pass outwards and forwards in connexion with the calcareous loop and the pallial lobules, running along the outer edge of the dorsal member of the former; they then turn back upon the reflected or ventral part of it, and on reaching the transverse portion bend inwards and doubling sharply upon themselves, again advance and go to form two vertical spirals turned towards the dorsal valve. The spirals are placed parallel to each other, and throughout the coil, consisting of two or three turns, they are united across the median line by a rather wide, stout, semi-cartilaginous membrane, which is attached behind to the transverse portion of the loop.

The arms are normally composed of a membranous tube or canal bearing a semi-cartilaginous grooved ridge[3]. The latter stretches from end to end of the former, and gives support to the fringe of cirri. As far back as the commencement of the spirals the arms are as above stated; but for the entire length of the lateral portions of the loop, where the arms are doubled upon themselves, and where, of course, two tubes or canals might have been expected, there is only one, the two having, as it were, coalesced.

[1] Plate LII. figs. 4, 5. [2] Plates LV. fig. 1; LVII. fig. 2. [3] Plate LVI. fig. 3.

These large canals at the roots of the arms are continuous with those of the spirals, and terminate in blind sacs, one at each side of the œsophagus, close to the mouth. On making a transverse section of this part of the arm[1], the enlarged terminal portion of the brachial canal is seen connected with the external edges of the dorsal and ventral members of the loop; and the pallial lobule, stretching between the inner edges, forms a sort of flattened inner tube. This inner tube opens widely into the perivisceral chamber, is in fact a prolongation of this chamber, and terminates at the anterior extremity of the lateral portion of the loop, forming what may be designated the brachial pouches.

At the proximal extremity of the arms the semi-cartilaginous grooved ridge is continued across the median line[2]. The cirri are inserted into an elevated base behind the groove, and in front of the latter there is a stiffish membranous fold, which runs along with it and the cirri to the distal extremity. This brachial fold rising from the edge of the groove forms it into a deep, narrow gutter, within which the mouth is situated at the posterior junction of the arms, the cirri of course being behind, the fold in front. The cirri are, there can be little doubt, clothed with vibratile cilia as in the *Polyzoa*, and the currents they excite will draw the nutrient molecules down into the gutter, along which they will be hurried to the mouth, the gutter itself being undoubtedly likewise ciliated.

The cirri are very fine, somewhat compressed on the contiguous sides, stiff and rigid towards the base, and tapering and delicate towards the tips, which are rounded; they are close-set and arranged in a double series, the cirri in each alternating. Hitherto they have been generally described as forming only a single series; but this is a matter of such easy demonstration, a single transverse section[3] of the arm being sufficient to prove that there are two, that it is difficult to understand how it ever came to be asserted that there was only one. The series is double throughout, not only in *W. australis*, but in all the other Brachiopods which have been examined on this occasion, namely, *W. cranium*, *Terebratulina caput-serpentis*, *Rhynchonella psittacea*, *Lingula anatina*, *L. affinis*, and *Crania anomala*.

The cirri are undoubtedly contractile to some extent, and are also endowed with the power of motion individually, as proved by the observations of Mr. Barrett[4]. It would likewise appear that the entire fringe of cirri can be elevated or depressed, there being ample means provided for the purpose. The walls of the brachial canal are tolerably well supplied with delicate muscular fibres, which run diagonally round the tube, and are most strongly developed towards the sides near the grooved ridge. An indistinct band of exceedingly delicate, longitudinal fibres may also be observed nearly opposite to it. I have, however, completely failed to discover anything like the double spiral arrangement of fibres described by Professor Owen[5], either in *Waldheimia* or *Rhynchonella*, and cannot but believe that this distinguished anatomist has been misled by the blood-sinuses, which are very numerous in the wall of the brachial canal, form-

[1] Plate LVI. fig. 2. [2] Plate LV. figs. 1, 2. [3] Plates LVI. fig. 3; LVIII. figs. 1, 2.
[4] *Op. cit.* [5] Introduction to Davidson's 'British Fossil Brachiopoda,' p. 10.

ing minute channels which run diagonally across the muscular fibres. And this belief is in some measure confirmed by the fact, that no mention is made of this beautiful and remarkable system of sinuses in any of the several memoirs on the subject published by that observer.

From the feeble nature of these brachial muscles it does not seem likely that in *Waldheimia* the spiral portion of the arms can be unrolled. The true function of the brachial canal would seem to be to sustain the grooved ridge bearing the cirri. As the canal is a closed tube, and as it undoubtedly contains fluid, a very slight contraction of its walls will render it firm and rigid. The coil may also, perhaps, be loosened a little by the same action; thus giving greater freedom to the cirri. The grooved ridge will in this way become firmly seated, so that its movements may be regulated with precision. These are effected by a very complicated piece of mechanism, which is rendered obvious on making a transverse section of the part, when the substance of the ridge is found to be fibrous, and the fibres to be arranged in several distinct groups[1]. One of these groups is situated at the outer margin of the base supporting the cirri, and has the fibres extending from these organs downwards. This is for the purpose of drawing back or elevating the fringe. A belt of similar fibres passes from the inner margin of the cirri, and running downwards, arches conformably with the groove, and passes up the inner side of the brachial fold. These fibres will contract the fold and draw it towards the cirri, thus narrowing the gutter. Another distinct group of fibres passes from this circular belt and the outer wall of the brachial fold, and descends to the lower surface of the ridge, where there is a thin stratum of muscular fibres. The action of this group will be to pull the fold forward from the cirri; and also when fully exerted to draw the cirri themselves forward, depressing them. The thin stratum of fibres will probably assist in the latter act.

The arms of *W. cranium* and *T. caput-serpentis*[2] are disposed in the same manner as in *W. australis*; and in the former the calcareous loop is precisely similar to that of the latter; but in *T. caput-serpentis* it is very much reduced, the extended lateral portions having almost entirely disappeared, little more than the transverse portion existing; and this, together with the crural processes, which are united below across the median line, forms a collar upon which the bases of the arms rest. In this species, therefore, the expanded lateral portions of the arms are without any apophysary support, and accordingly other means are provided for sustaining them. The two produced lobules of the dorsal pallial lobe reach to the ends of these portions of the arms as in *W. australis*; and are stiffened with numerous, imbedded, calcareous spicula to such an extent, that when the soft tissues are removed by maceration the form of the parts remains unaltered. The spicula extend also over the surface of the inner lamina of the pallial lobe, and pervade likewise the walls of the canal, and even the cirri; so that the brachial apparatus becomes firmly fixed, and in this way a substitute is found for the usual apophysary support.

[1] Plate LVIII. fig. 2.

[2] Plate LV. fig. 2.

The arms of *R. psittacea* are[1] totally deprived of calcareous support except at their origin, where they are sustained by the two hinge-processes, or oral laminæ, the points of which reach as far forward as their external margins. They fill up the greater portion of the pallial chamber; and in their arrangement accurately resemble the calcareous spirals of *Atrypa reticularis*, a Silurian fossil, only their approximate sides are not flattened. The arm throughout is composed of a slightly depressed tube or canal, carrying along its outer margin the semi-cartilaginous grooved edge, bearing the fringe of cirri as in *W. australis*. The brachial fold in front of the groove is largely developed, and completely overlaps it. The tube or great brachial canal terminates at the side of the œsophagus in a delicate membranous sac of no great extent, which projects into the perivisceral chamber, as first noticed by Professor HUXLEY. The use of these sacs is not obvious, though perhaps they may be in some way connected with the limited movements of the arms; or it is not altogether unlikely that they are for the purpose of increasing the surface through which the fluids contained in the canal and chamber may act upon each other.

The parietes[2] of the great canal are somewhat stouter than in *W. australis*; the muscular fibres, however, are arranged in the same manner as in it, but are more numerous, particularly the longitudinal ones, which form a well-defined band towards the proximal extremity of the arm. There is not here, any more than in the *Terebratulidæ*, any trace of a double spiral disposition of fibres; nor is there any more reason to suppose that the brachial organs can be unrolled. The primary, if not the only, use of the contractility of the walls of the great canal, would appear to be, in *Rhynchonella* as well as in *Waldheimia*, to reduce the calibre, and by the pressure of the contained fluid to stiffen the organ so that the grooved ridge and cirri may be brought into play. A slight opening of the coil most likely takes place, and the band of longitudinal fibres seems to indicate that the first coil, at least, may be to some extent drawn in, and thus perhaps the whole brought closer up to the posterior wall of the pallial chamber. But it must not be overlooked that longitudinal fibres appear necessary to the complete action of those destined to compress the canal by preventing any tendency to the unrolling of the coil.

Professor OWEN, however, has expressed an opinion that the multispiral arms of *Rhynchonella* and *Lingula* can be unrolled and thrust out of the pallial chamber; and that in the latter genus they probably assist in opening the valves; likewise that the coiled portion of the arms of the *Terebratulidæ* can be so far unrolled, as in like manner to react upon the closed valves of the shell[3]. Such an opinion seems scarcely tenable.

A large development of the brachial apparatus seems necessary in the economy of the animal, and the various ways in which it is folded up and disposed within the pallial chamber are only so many methods of arranging within a limited space the requisite extent of organ. And there is sufficient proof, in several fossil genera, that the unrolling

[1] Plates LV. fig. 3; LX. fig. 3; LXI. fig. 2.

[2] Plate LX. fig. 9.

[3] Trans. Zool. Soc. vol. i. p. 150, 1835; and Introduction to DAVIDSON'S 'British Fossil Brachiopoda,' pp. 10, 11.

of these organs is not essential to the performance of their functions. In *Atrypa*, for instance, in which the arms were rolled exactly as in *Rhynchonella*, the calcareous support prohibited not only the unrolling, but any movements whatever of the coil. It would therefore certainly be erroneous to conclude that in the latter it is necessary to the due exercise of their function, that they should be thrust unrolled out of the shell. Such an opinion can only be maintained on the ground that a special apparatus is provided for the purpose, or that direct observation shows it to be correct. We have seen, however, in this form, that no such apparatus is really in existence; and with regard to observation, we have the evidence of Mr. BARRETT[1], who had frequent opportunities of examining the animal alive, but never saw the arms in the least degree protruded.

That the arms are instrumental in opening the valves is equally improbable, as special means are provided for this purpose in both the articulated and unarticulated Brachiopods.

In *Lingula anatina* the brachial organs[2] are strong and fleshy, and rise from the back of the pallial chamber in the usual manner. They are entirely without calcareous support, even at their origin; and form two spiral coils, with six or seven turns each, directed inwards and upwards. The arms are very thick at the base, taper more suddenly than in the articulated species, and terminate in fine points. On making a transverse section[3] they are found to differ in organization from those of *Rhynchonella*, to which, externally, they bear the strongest resemblance. Instead of one, as in that genus, there are two great brachial canals, which may be denominated respectively the anterior and the posterior. The former is the equivalent of the great canal in the other Brachiopods, and, like it, terminates at the side of the œsophagus in a blind sac. It is pretty regularly cylindrical, with the walls excessively thick, being composed, for the most part, of a white cartilage-like substance, which is most developed towards the side opposite the cirri. These latter organs are supported upon a semi-cartilaginous grooved ridge, which is very similar to that in *Waldheimia*, and in like manner supplied with a very ample brachial fold. Muscular fibres are also provided for the movements of these parts; but the fibres, though very similarly arranged, are not so extensively developed. This canal is lined with a muscular stratum, the fibres of which run in a transverse direction in the vicinity of the brachial fold; elsewhere they are longitudinal or slightly diagonal.

The posterior canal is much flattened, and stretches along the inner surface of the arm, extending from the base of the cirri half-way round it. This canal has the appearance of being formed by a process of the pallial membrane similar to that which extends along the lateral portions of the loop in *Waldheimia*. The posterior canals of the two arms terminate at the sides of the œsophagus behind the anterior canals, and are separated from each other by a considerable space, which is divided on the median line by a delicate, membranous septum. The two chambers thus formed communicate with the perivisceral cavity, by two small oval orifices[4] placed one on each side of the septum;

[1] *Op. cit.* [2] Plate LXIV. fig. 3. [3] Plate LXV. figs. 7, 8. [4] Plate LXVI. fig. 4.

these orifices open into the cavity close behind the œsophagus, and directly above a transverse fold of the anterior wall of the body. It is not altogether unlikely that these chambers likewise communicate with the posterior canals, but I have failed to ascertain the fact; and VOGT[1] also states that the two canals of the arm are cut off from the perivisceral cavity. Above the orifices there is another delicate membranous fold or flap, which seems capable of closing them by being pressed down against the parietal fold, to which the occlusor muscles are attached, acting in the manner of a valve.

The membranous wall of the posterior canals is composed of two layers, an outer homogeneous, and an inner muscular layer, each having its proper epithelium. The fibres of the latter layer run, for the most part, diagonally across the canal, becoming transverse towards the part furthest from the grooved ridge. Here there is also projecting into the canal a stout muscular band of a brown colour with the fibres longitudinal, and extending the whole length of the organ. Throughout it is firmly attached to the wall of the canal, and terminates at the root of the arm.

The additional mechanism in connexion with the arms of *Lingula* undoubtedly implies some peculiar function; and in this genus it may be fairly inferred that the brachial organs are capable of being evolved, if not entirely, at least to a considerable extent.

The posterior canals, which are only found in *Lingula*, appear to be the principal agents in this operation. These will be able to act without interfering with the movements of the grooved ridge and cirri; when their walls are contracted and the longitudinal muscular belt relaxed, the fluid, which they undoubtedly contain, will cause the arms to uncoil, and on the walls relaxing and the muscle coming into play, they will again be withdrawn and coiled up. But the animal must be seen in a living state before it can be ascertained to what extent these organs are unrolled and protruded.

This appears to be the explanation of the action of these parts; but whether exactly correct or not, it seems clear enough that the arms of *Lingula* have the power of extension in a greater or less degree. And from the deficiency, in the *Terebratulidæ* and *Rhynchonellidæ*, of the apparatus here employed, it may safely be concluded that in them the brachial organs are deprived of any such movement.

The anterior canals in *Lingula* will perform the same office as the great canals do in the other Brachiopods; that is, they will give firmness to the parts, so that the cirri and brachial fold may be brought into play. When the arms are retracted, the walls of these canals, which it will be remembered are closed tubes, will relax a little to relieve themselves from the pressure of the contained fluid; when they are extended the walls will contract to maintain the required pressure. Thus the cirri and brachial fold will be under the control of their proper muscles, however much or little the arms may be extended.

The arms of *L. affinis*[2] are perfectly similar to those of *L. anatina*, only the thickened portion of the wall of the anterior canal is much more limited.

The mouth[3], in all the Brachiopods, as previously stated, is situated in the brachial

[1] *Op. cit.* [2] Plates LXV. fig. 6; LXVI. figs. 2, 3. [3] Plates LV. figs. 2, 3; LXIV. fig. 3.

groove, at the posterior junction of the arms, and is a simple, oval, transverse slit, or orifice devoid of any armature. In *W. australis* there is, however, a slight bulging out of the posterior wall immediately within the orifice, which is somewhat like the valvular appendage in *Plumatella*, and may perhaps assist in swallowing. The alimentary tube[1] assumes the form of a siphon bent in the vertical plane, the arch turned towards the dorsal valve; the œsophagus represents the short, the stomach and intestine the long arm.

The œsophagus is of no great length; it is depressed as it passes through the wall of the body, and is afterwards slightly compressed; it ascends from the oral aperture, having the points of the crural processes on each side behind, and, inclining backwards, passes between the occlusor muscles; at some little distance from the dorsal valve it suddenly bends backwards and downwards, and opens into the anterior extremity of the stomach, which is of an elongated form, somewhat wider than the œsophagus, and about as long. The stomach contracts gently behind towards the intestine; this latter being at first about as thick as the commencement of the alimentary canal. It continues to descend at the same inclination as the stomach, and tapering downwards passes between the divaricator muscles towards the ventral valve, immediately behind the termination of the occlusors, and in front of the accessory divaricators, where it terminates in a rounded point. This point[2] is attached to the parietes, or lining membrane of the perivisceral chamber, and is imperforate; consequently there is no anal outlet in this species.

The walls of the whole canal are exceedingly firm; they never collapse, and are provided with a fibrous outer coat, and an inner mucous membrane. In the œsophagus the latter is comparatively delicate, and is raised into a few, not very conspicuous, longitudinal folds[3]; in the stomach the plications have also a longitudinal tendency; but they are not numerous, and are somewhat broken up into irregular rugæ. The lining membrane is exceedingly thick in the intestine, and is produced into four or five very large, longitudinal plaits[4], which project almost as far as the centre of the channel. The fibres of the muscular coat of this portion of the alimentary canal are transverse. The whole of the mucous membrane is extremely friable, and is consequently rarely observed entire, especially in the intestine, where, unless the specimens be in a good state of preservation, it is always broken up, and escapes, in fragmentary masses, on opening the tube. The specimens examined by Professor Owen must, in this way, have lost the lining membrane, or the "muco-epithelial lining" could never have been described as "disposed in very delicate transverse plates[5]." And indeed the illustrative figure seems to prove this.

The liver[6], of a greenish colour, is composed of a congeries of ramified cæcal tubes; it lies between the dorsal extremities of the occlusor muscles, concealing the greater portion of the œsophagus and stomach, and is divided into two lateral portions, one on each

[1] Plates LII. fig. 10; LVI. fig. 1; LVII. figs. 1, 2.
[2] Plate LIV. figs. 8, 9.
[3] Plate LVI. fig. 6.
[4] Plate LIV. figs. 10, 11.
[5] Introduction to Davidson's 'British Fossil Brachiopoda,' p. 13. pl. 1. fig. 4.
[6] Plates LII. figs. 1, 10; LVII. figs. 1, 2.

side of the alimentary tube, by a membrane denominated the mesentery. Each portion is subdivided into an anterior and posterior lobe, which pour their secretion through the dorsal wall, into the cardiac end of the stomach, by two or three short, distinct ducts, which are formed by the confluence of the various ramuscules[1] composing the lobes. The terminal cæcal extremities of the tubes are rounded, and as seen at the surface, generally give to the organ the appearance of being made up of globules. The parts, though closely pressed together, are not united, each ramuscule and tube being free. The anterior lobe is much the larger, and extends in front below, into the commencement of the brachial pouches; and above, as far as the opening of the central pallial sinus; the posterior extremity extends below the stomach, reaching backward beyond the pyloric termination. The posterior lobe lies on the dorsal surface of the stomach behind the anterior lobe, and reaches as far backward as the gastro-parietal band.

It has been already stated that the alimentary tube is composed of an inner and an outer membrane; these are its proper walls; there is, however, another membrane external to both, sheathing the entire tube very closely throughout, except at the anterior extremity of the œsophagus. This sheath gives off several delicate membranous bands, which go to the parietes of the perivisceral chamber, suspending the alimentary tube in its centre. These bands have been named respectively by Professor HUXLEY[2], who first described them, the mesentery, the gastro-parietal and the ilio-parietal bands.

The mesentery is divided into two portions, the dorsal and ventral; the latter extends from the lower or anterior face of the intestinal tube and stomach, to the posterior face of the œsophagus and the confluent extremities of the occlusor muscles, and passes above the lower portion of the intestine as a narrow free edge. The dorsal portion extends from the dorsal face of the stomach and anterior wall of the chamber to its upper wall, running along from end to end of the septum of the dorsal valve. The mesentery, therefore, sustains the alimentary canal in the vertical plane, and together with it divides the anterior portion of the chamber into lateral halves.

The gastro-parietal bands are three in number, two lateral and one median. The lateral ones pass from the sides of the stomach, ascending outwards and forwards to the dorsal extremities of the posterior occlusor muscles, around which they form an imperfect sheath. The median gastro-parietal band has hitherto escaped notice; it originates at the upper surface of the stomach, between the lateral pair, and passes upwards and backwards to the dorsal wall, a little in advance of the hinge-plate; it is very short. All these three bands originate in a ridge which stretches from side to side of the dorsal aspect of the stomach.

The ilio-parietal bands are prolongations of two narrow lateral expansions, which extend from the sides of the stomach to some way down the intestine; they pass outwards and upwards, and go to the sides of the chamber a little below the junction of the two pallial lobes. These bands give support to the inner portion of the peculiar organs denominated hearts by Professor OWEN.

[1] Plate LVIII. figs. 9, 10.

[2] Proceedings of the Royal Society, vol. vii. pp. 109, 110 (1854).

It will afterwards be seen that these bands, in connexion with the alimentary canal, have more important functions to perform than that of merely suspending it in the perivisceral chamber.

The digestive organs are so similar in the other two species of the *Terebratulidæ* which have been examined, that it is not necessary to say much in respect to them. In *T. caput-serpentis*[1] there appears to be only two hepatic ducts, and both in it and in *W. cranium*[2] the intestine is very short, terminating in a blind sac before it reaches the ventral wall of the perivisceral chamber. It tapers gradually to a point which is rounded, and suspended in its place by the mesentery[3]. The mucous membrane, lining the intestinal tube of *W. cranium*, is exceeding thick, and produced into five or six excessively stout, longitudinal folds, which in transverse section[4] exhibit a pyramidal contour, their apices almost meeting in the centre of the tube. In *T. caput-serpentis* the lining membrane is also very thick; but from the state of the specimens examined the character of the plaits could not be determined.

In *R. psittacea* the disposition of the alimentary canal[5] is the same as in the *Terebratulidæ*. The œsophagus is, however, considerably longer than in *Waldheimia*, the mouth approaching much nearer to the ventral valve. The liver[6] is larger than usual, and the biliary secretion is conveyed through the lateral walls of the cardiac extremity of the stomach by four short ducts, two at each side, one being placed a little in advance of the other.

The intestine is rather long and gradually tapers downwards. On reaching the ventral valve, directly behind the extremities of the occlusor muscles, it turns backwards and upwards, and, detaching itself from the mesentery, advances a little, and terminates in a much enlarged, rounded extremity, which inclines to the right or left, varying in this respect in different individuals. The termination projects freely into the centre of the perivisceral chamber, and here, as in the *Terebratulidæ*, there is no anus; the bulbous enlargement[7] is entire, exhibiting no opening whatever. This is perfectly obvious in *Rhynchonella psittacea*, in which the facilities of examination are comparatively great, on account of the terminal portion of the intestine being free and projecting into the perivisceral cavity. I have, nevertheless, made every endeavour to find an anal perforation, both in this and in the *Terebratulidæ*. I have made numerous dissections under a powerful doublet; I have removed the part and examined it with the microscope; I have filled the tube with fluid as a finger of a glove with air, and by pressure have attempted to force a passage; I have tried injections; but have equally, on all occasions, failed to discover an outlet, and have only succeeded in demonstrating more and more clearly the cæcal nature of the terminal extremity of the alimentary canal. Therefore, how much soever it may be opposed to analogy and to authority, the fact must be recorded—there is no anal orifice in *Waldheimia*, in *Terebratulina*, or in *Rhynchonella*.

In *Rhynchonella* the gastro-parietal and ilio-parietal bands, particularly the latter, are

[1] Plate LIII. fig. 5. [2] Plate LIV. fig. 2. [3] Plate LIV. figs. 3, 4. [4] Plate LIV. figs. 5, 6, 7.
[5] Plate LXI. figs. 1, 2. [6] Plate LXI. figs. 3, 4. [7] Plate LX. figs. 4, 5.

longer than in *Waldheimia*. The last-mentioned bands, too, are united across the intestine, their posterior margins being continuous and free. And not only these, but the gastro-parietals likewise sustain the inner extremities of two pseudo-hearts, of which in this genus there are four.

The alimentary tube in *Lingula*[1] presents two or three interesting modifications. The mouth is perfectly similar to that of *Waldheimia*, and the œsophagus, which is somewhat elongated, is at first depressed; but on emerging backwards from between the anterior occlusors, becomes compressed. The stomach is short, being almost lenticular, and the transverse dorsal ridge is much produced. In front it is slightly convex, where it receives the œsophagus; behind it is a little produced, and an inconspicuous constriction marks the commencement of the intestine, which running backwards, buried beneath the lobules of the liver, and resting above the posterior adjustor muscles, gradually descends towards the ventral lobe, immediately in front of the divaricator muscle. This straight portion of the intestine corresponds to the entire intestine of the articulated Brachiopods, and it thus appears that in *Lingula*, as well as in them, the first inflection of the intestinal tube is towards the ventral surface. From thence the tube bends to the left, and turning forwards and upwards, forms two large loops at the posterior portion of the perivisceral chamber; it then advances along the right side, and, dipping under the dorsal extremities of the adjustor muscles and the pseudo-heart, opens through a nipple-like anus[2] situated at the right side of the body between the margins of the mantle. The anal orifice is ample, and is very easily distinguished; it is placed considerably nearer to the dorsal than the ventral surface. The calibre of the alimentary canal does not vary much; the stomach only being a little enlarged. The mucous membrane is very stout in the œsophagus, stomach, and anterior portion of the intestine. In the former it is produced into very large, prominent, longitudinal folds, which appear to be continued into the stomach; but this point could not be clearly ascertained; in the anterior or straight portion of the intestine the longitudinal plaits seem almost to have disappeared, but very delicate transverse rugæ are discernible[3]. Similar, though still more minute, rugæ are found in the convolutions, where the lining membrane is thin. The muscular coat of the intestine is well supplied with transverse fibres.

The alimentary tube in *Lingula*, like that in the articulated Brachiopods, is sheathed in a transparent, homogeneous envelope, from which originate certain membranous bands, that pass to the parietes of the perivisceral chamber. These bands are the homologues of those already described in the other forms, under the designations of the mesentery, the gastro- and ilio-parietal bands.

The mesentery in *Lingula* is in a very rudimentary condition, it being represented merely by two narrow membranous expansions stretching along the upper and under surface of the œsophagus, from the biliary ducts to the anterior parietes: the dorsal mesenteric band is prolonged between the anterior occlusors. The gastro-parietal bands pass from the transverse ridge of the stomach, one on each side, to the posterior surface

[1] Plates LXIV. figs. 3, 4; LXV. figs. 1, 3, 4. [2] Plate LXVI. fig. 3. [3] Plate LXIV. figs. 6, 7.

of the dorsal extremities of the posterior occlusors. These bands are less extensive than their counterparts in *Waldheimia*, and do not sheath the muscles as in it. They support, however, stout muscular processes, which pass inwards from the parietes towards the stomach. There is no central gastro-parietal band, the lateral ones being separated by a considerable space. The ilio-parietal bands are very largely developed; they extend along the sides of the straight portion of the intestine, and expanding backwards give off each a process which passes to the side wall of the perivisceral cavity. These processes give support to the pseudo-hearts, and then turning forward stretch along the inner margins of these organs from end to end, forming a broadish expansion, projecting into the perivisceral cavity. The bands themselves terminate behind at the right side of the ventral extremity of the divaricator muscle, tying down the posterior end of the straight portion of the intestine. The terminal extremity of this tube is likewise attached to the lateral wall by a membrane, which extends as far back as the divaricator muscle.

The liver is composed of ramified cæca, and is of a greenish colour, as in all the Brachiopods. The cæca, however, are smaller than usual, and are formed into dense, irregular lobules, which communicate with the alimentary canal by four short, very wide ducts. The largest portion of this organ lies above the canal and behind the stomach, and pours its secretion into the upper end of the intestine by two lateral ducts; that on the left being a little in advance of the other. A duct from a few small lobules, situated between the posterior occlusors and above the œsophagus, opens through the dorsal wall of this portion of the canal, a little in advance of the stomach. A considerable mass of the hepatic organ, lying below the alimentary canal, communicates with the stomach by a large duct, which penetrates its lower wall.

The *Infusoria* appear to be the chief food of all the Brachiopods; perhaps the only food of the articulated species. In the stomach and intestine of the latter siliceous cases of the *Diatomaceæ* are almost always found, and sometimes in abundance. *Lingula*, however, appears to be a more general feeder, its intestine frequently containing a vast variety of matter. Siliceous cases of *Naviculæ* and other *Diatomaceæ* are very common; small crustacea also occur, and the spicula of sponges; besides a large quantity of dark coloured matter mixed with setæ, probably of annulose animals, and apparently with particles of sand or mud; something like vegetable matter may also be detected. The convolutions of the intestine are generally filled with fæcal refuse, rolled into numerous round or oval pellets. No fæces are ever found in the intestine of the articulated Brachiopods.

Reproductive System.

The Brachiopods are usually considered to be diœcious, and the sexual organs, which in the *Terebratulidæ* occupy the great pallial sinuses,—the so-called vascular trunks,—are stated to be ovaries or testes, according to the sex of the individual. There is, however, some reason to doubt the accuracy of this conclusion; though it is to be lamented that nothing of a very positive nature can be brought to bear upon this question.

In *W. australis* the genitalia[1] are formed of thick bands, somewhat convoluted and branched; they are of a full yellow colour, and are thrust into the trunks and main branches of the great pallial sinuses. There are four of these bands, two in each lobe; those in the dorsal lobe are single and occupy the two outer or lateral sinuses, extending from behind the attachment of the occlusor muscles to within a short distance of the anterior margin of the mantle: their posterior extremities reach to the perivisceral chamber. The ventral pair extend as far forward as the dorsal, and are double, that is, each forms a loop, the free extremities of which pass into the outer and inner sinuses of the same side; the looped portions lie within the perivisceral chamber, at the sides below the pseudo-hearts or oviducts.

These genital bands are attached to the inner lamina of the mantle throughout their whole extent, by a membrane[2], which, originating in this lamina, passes into a groove extending along the under surface of the genital band. The genital or pallial artery[3] runs along the edge of this membrane, and has the reproductive organ developed around it. This is the obvious disposition of the parts as apparent on a general examination; but on a closer inspection there can be little doubt that these organs are developed, in reality, between the two membranes, which, it will afterwards be seen, compose the inner lamina of the mantle, and, bulging out the interior of these, become suspended, as it were, in the pallial sinuses.

The organs themselves vary considerably in size and in the extent of their ramifications, chiefly on account, apparently, of their state of development, though not entirely so: as even when the ova are mature there is occasionally a remarkable diversity. In two individuals that were examined, in which the ova were fully developed, the genital bands in one were nearly twice as wide as in the other. In other specimens, in which these organs were comparatively small, ova were distinguishable; but in some none could be seen. Those in which ova are deficient are generally supposed to be the male secreting organ. The form, colour, and general appearance of these eggless bands do not differ from those charged with ova; and they certainly have very much the character of undeveloped ovaries. Moreover, the genitalia are very perceptibly composed of two elements, the yellow, ovigerous substance, which forms the chief mass; and a red material, which is for the most part distributed over the surface of the organ. When the organ is in a low state of development, this red matter forms a narrow, irregular cord[4], which runs along the sides of the band, and is occasionally spread over the surface in spots and blotches. When the ova are mature, this substance can still be traced as small specks on the surface and throughout the mass. From what will be shortly stated, with regard to the genitalia in *Lingula*, it seems probable that this red matter may prove to be the testis.

The minute structure of these organs has not been sufficiently examined; it may be stated, however, that the ova appear to be developed in cells, and that when the yellow mass, which is deficient of eggs, is broken up and placed under the microscope, it is found

[1] Plates LII. figs. 1, 2, 3, 10; LVII. fig. 1.
[2] Plate LV. fig. 1.
[3] Plate LVI. fig. 4.
[4] Plate LIII. fig. 8.

to be composed almost entirely of minute, clear granules. The red substance is likewise found to be made up of large, irregular cells, inclining to oval, very variable in size, and without any apparent nucleus.

In *W. cranium* the genitalia[1] are arranged precisely as in *W. australis*, only the bands do not extend so far forward, and are of a pale yellow colour. The red matter is also present, sprinkling the surface with distant, round spots. The bands are very finely granular, and in no instance have I detected eggs in them. It is therefore probable that those examined were out of season.

T. caput-serpentis exhibits a somewhat different arrangement of these organs[2]. In this species they are placed in large sinuses situated in the pallial lobes, one at each side. These sinuses are, however, nothing more than the enlarged trunks of the so-called pallial vessels or great pallial sinuses. They are four in number, two in each lobe; and the genital band which is placed within them forms a thick, convoluted layer, with small spaces between the folds. The convolutions are grooved throughout on the under surface, and the suspending or genital membrane[3] passes into the groove, as it does in *Waldheimia*; and here, consequently, it forms a complete network. This layer is of a rosy salmon-colour when the animal is alive, but in spirit-specimens is yellow. The walls of the sinuses are held together by numerous muscular ties, which pass directly from the one to the other, through the spaces left between the convolutions of the band. The ventral sinuses are the larger. When in an immature state the bands appear to be composed of rather large, circular vesicles, within which the eggs are probably developed.

The reproductive organs have much the same disposition in *Rhynchonella psittacea*; but the dorsal genital sinuses are not connected with the so-called vascular trunks, while the ventral are. The genital band[4], too, which is yellow, is much more closely convoluted, having sometimes almost the appearance of being fused into one mass, the interstices being just sufficient to permit the passage of the muscular ties, which are stout, and are arranged in imperfect longitudinal and diagonal lines. These ties give a granulated or pitted appearance to the ovarian impression in the shell, and are worthy of the attention of the palæontologist. The sinuses are limited to the posterior half of the lobe, while in *T. caput-serpentis* they advance much beyond the centre. The genitalia in *R. nigricans* are arranged in precisely the same manner as in *R. psittacea*.

In *Lingula*, the only form of the unarticulated Brachiopods in which I have examined the reproductive organs[5], they are withdrawn altogether from the mantle, and are placed in the perivisceral chamber, as they are stated to be in *Discina*. In the former these organs are very bulky, occupying a very large portion of the chamber; they lie for the most part behind the liver, and, as has been already stated, surround the alimentary tube; they form four irregularly lobulated or branched masses, two above and two below the tube; these pairs may be denominated respectively the dorsal and ventral ovaries.

[1] Plate LIII. figs. 3, 4.
[2] Plate LIII. figs. 1, 2.
[3] Plate LV. fig. 2.
[4] Plates LX. figs. 1, 2, 3; LXI. fig. 1.
[5] Plates LXIV. figs. 1, 2, 4, 5; LXV. fig. 3.

When in a highly developed state the lobes or branches insinuate themselves between and around the muscles, so that it is almost impossible to trace the relation of these organs to the other parts; but when immature it is very easy to do so. The dorsal ovaries are then found to be suspended by the ilio-parietal bands, the ventral by the continuation of these bands along the free margins of the pseudo-hearts or oviducts. In both cases the attachment is along the margins of the bands, which are related to the genitalia much in the same manner as the suspending membrane is to the genital bands in *Waldheimia*; and it would seem that in *Lingula* the reproductive organs are really developed between the two layers composing the ilio-parietal bands. There can be no doubt that these masses, which are of a reddish-yellow colour, are the ovaries; they resemble very much in structure the genital bands in the *Terebratulidæ*, and, as in them, they are found occasionally to contain eggs, but are frequently devoid of them. In one, in which these organs were filled with fully-developed ova, the red substance before alluded to was present. In *Lingula*, however, it assumes a different form: in this it is a dendritic or branched organ[1], spread over the external surface of the ovarian masses. On the dorsal ovaries the branches pass from behind forward in two lateral divisions; on the ventral ones in three, one being median, two lateral. The branches, which are quite irregular, do not diminish in thickness towards their extremities. On removing the thin transparent membrane which forms the dorsal and ventral walls of the perivisceral chamber, these dendritic organs came away with it, and I was originally induced to believe that they were organically connected with it; but further experience has led to the conclusion that they are really a portion of the genital mass, and that from the pressure of the valves, on their being closed, they had become accidentally adherent to the membrane.

On examining a portion of this branched organ[2] with the microscope, it was found to be composed of large irregular cells, somewhat elliptical in form, and closely resembling those of the red substance in connexion with the genitalia in *Waldheimia*. The cells, however, in *Lingula* appeared to present different stages of development, varying much in size and form. Some were ovate, others perfectly elliptical; the larger ones were pointed at both ends, and exhibited a double line in the centre, placed longitudinally; while the largest, measuring $\frac{1}{180}$ths of an inch in length, were fusiform, with the extremities more or less sharply pointed. These corpuscles[3] were filled with numerous, delicate, hair-like bodies, resembling spermatozoa. From these facts it can scarcely be doubted that the dendritic organ is the testis, and that the fusiform cells are fully developed spermatophora, containing spermatozoa. It would thus seem fair to conclude that *Lingula*, at least, is androgynous; and if the red matter in connexion with the genitalia in the articulated Brachiopods should prove to be the same as the dendritic organ in the former, then in them also the sexes are combined.

Professor OWEN supposes that the ova, when mature, escape by the dehiscence of the pallial membranes[4]. So long as no passage was discovered leading externally from the

[1] Plate LXIV. figs. 1, 2. [2] Plate LXVI. fig. 8. [3] Plate LXVI. figs. 9, 10.

[4] Introduction to DAVIDSON's 'British Fossil Brachiopoda,' p. 22.

perivisceral chamber, this would appear to be the only possible conclusion, but can now be no longer maintained, for it has been ascertained that more than one such passage exists. The natural inference would therefore seem to be, that the eggs will find their way through these passages, which may consequently be looked upon as oviducts.

These curious organs were originally described by CUVIER as hearts, in his well-known memoir on *Lingula anatina*[1], and subsequently by Professor OWEN in the Brachiopoda generally, in his equally celebrated paper "On the Anatomy of the Brachiopoda," published in the Transactions of the Zoological Society[2]. And up to the present time these organs are generally considered as the blood-propelling instruments. They open, however, as before stated, externally, and therefore can have nothing to do with the vascular system. Any one who has the opportunity, and will take the necessary pains, may satisfy himself of this fact; but he must not be discouraged by a failure or two, for unless the specimens be in excellent condition, he will find the determination of even this simple point attended with considerable difficulty. The epithelium, which is very deciduous and brittle in spirit-specimens, is liable to be crumpled in the vicinity of the external orifices. It is consequently a matter of no little nicety, under such circumstances, to ascertain if the openings pass through the epithelium. It was on account of my inability to prove this that I hesitated with regard to these orifices for some time, even after they had been traced through the membrane circumscribing the perivisceral chamber. And as the subject had been investigated by anatomists of the very highest reputation, it was necessary, before calling in question the accuracy of their conclusions, to have the most positive evidence. I therefore persevered, not only until the passage was demonstrated over and over again, but until the exact position and form of the aperture were determined beyond the possibility of doubt.

There are two of these oviducts in all the Brachiopods that have come under my observation, except in *Rhynchonella*, in which there are four, as first pointed out by Professor HUXLEY. In the *Terebratulidæ* they lie within the ventral valve[3], and may be described as tubes of no great length, composed of two well-marked portions, one being expanded and laminated, the other more strictly tubular[4]; these parts are respectively the auricle and ventricle of Professor OWEN. The latter is placed between the two membranes forming the anterior wall of the perivisceral chamber, is curved a little inwards, and, tapering to an obtuse point, opens externally a short way below the mouth, at some little distance from the central line[5]. These orifices are by no means minute, and are in the form of slits placed diagonally, having the occlusor muscles between them. The laminated portion lies within the perivisceral chamber, and is much expanded, the lips turning over like those of a trumpet, and having the inner surface covered with strong, radiating, pectinated laminæ. In *W. cranium* the laminæ are smaller than usual, and are very regular. The expanded portions are placed one at each side of the intestine,

[1] *Op. cit.* p. 8.

[2] Likewise in the Introduction to DAVIDSON's 'British Fossil Brachiopoda,' pp. 14, 15.

[3] Plates LII. fig. 10; LIII. fig. 5; LIV. figs. 1, 2; LVI. fig. 1; LVII. figs. 1, 2.

[4] Plate LIII. figs. 9, 10.

[5] Plate LV. figs. 1, 2.

their inner margins being supported by the ilio-parietal bands, and their outer soldered to the lateral walls of the body; they open upwards and backwards in the plane of the dorsal or posterior surface of the intestine.

On laying these organs open, the laminæ of the expanded portion are found not to extend far down, and to end abruptly; the lining of the tubular portion is thick, slightly wrinkled longitudinally next the laminated portion, and raised into minute, obtuse villi. The whole of the organ is of a yellow colour, except in *W. australis*, in which the tubular portion is reddish.

It has been already stated that in *Rhynchonella* there are four oviducts[1], two within the ventral, and two within the dorsal valve; both pairs are precisely similar, and are of a yellowish colour. The tubular portion, or that which lies between the two layers of the parietes, is ovate-oblong, and has the lining membrane raised into strong, principally longitudinal, wrinkles[2]. The expanded extremity, though comparatively small, is well marked, being placed rather laterally, and separated from the broad, rounded end of the tubular portion by a constriction; the laminæ are few and branched. The ventral pair[3] correspond to the two in the *Terebratulidæ*, and open externally at the pointed extremity, through a slit situated as in them; and the inner expanded portion opens through the ilio-parietal bands, near to their junction with the walls of the body, being held within them, as aptly remarked by Professor HUXLEY, like a landing-net in its hoop. The dorsal ones[4] lie on each side of the liver, and their external orifices, which are above the mouth, open downwards as in the other pair. Their expanded extremities are suspended by the gastro-parietal bands close to the walls of the chamber; they open upwards and forwards.

In *Lingula*[5] the oviducts are rather peculiar in form, though essentially the same as in the articulated Brachiopods; they are two in number, and are the homologues of the ventral pair in *Rhynchonella*, and consequently equivalent to those in the *Terebratulidæ*. They lie, to a great extent, between the two layers of the ilio-parietal bands, and are stretched along the lateral walls of the perivisceral chamber from the front to behind the dorsal attachment of the adjustor muscles, and are so concealed by the viscera and muscles that very little of them can be seen until those parts are removed. The expanded portions open upwards and towards the lateral walls of the body through the processes of the ilio-parietal bands close to the side walls of the chamber. They are of a yellowish colour, small in proportion to the other part, puckered a little, and irregularly and widely laminated in the interior. The tubular portions are united posteriorly to the former by exceedingly short, constricted necks, and are much flattened or depressed; behind they are enlarged and angulated, and are attached by their outer margins to the parietes of the chamber; their inner margins projecting inwards give support to the folds of the ilio-parietal bands, which suspend the ventral ovaries; they taper gradually forward, and, curving in conformity with the anterior wall, penetrate its substance

[1] Plate LXI. figs. 1, 2. [2] Plate LX. figs. 7, 8. [3] Plate LX. fig. 3.
[4] Plate LV. fig. 3. [5] Plates LXIV. figs. 2, 5; LXV. fig. 1.

as two rather delicate tubes; and thus buried run for some distance towards each other, and terminate at the external surface in two small diagonal slits[1], one a short way on either side from the median line, a little below the mouth. The expanded portion is yellowish, and the tubular of a full red colour. The walls have a glandular appearance, the inside being velvety from the numerous minute villi which crowd the surface.

From the nature of these organs it seems probable that the ova, on their passage outwards, may receive some external covering; or perhaps, having to subserve the function of renal organs, as suggested to me by Professor HUXLEY, their walls are necessarily glandular. Be this, however, as it may, they seem to be primarily for effecting the discharge of the eggs, and therefore the denomination of oviducts appears appropriate. In corroboration of this view of their function it may be stated, that in two instances, in which the ova were mature, they were found in vast numbers strewed about the perivisceral chamber, and in one of the oviducts several had penetrated almost to the external orifice. The expansion of the inner aperture may be for the better securing the ova as they fall into the chamber; and it is not improbable that ciliary currents may direct their course to this receptacle. Arrived there, they are probably carried onward by some peristaltic action of the parts, for such would seem necessary; as the tubular portion, being buried in the parietes, will be kept in a state of collapse by the pressure of the fluid in the perivisceral chamber. The passage is undoubtedly so constructed as to be opened and closed as the economy of the animal requires.

CIRCULATORY AND RESPIRATORY SYSTEMS.

The circulatory apparatus has been, up to a very recent period, entirely misunderstood. Professor HUXLEY's paper, which appeared in the Proceedings of the Royal Society in 1854, threw the first gleam of light upon this most intricate portion of the anatomy of these animals. In 1852 I had discovered that the Cuvierian hearts open externally, and in my communication on the subject submitted to the British Association in 1856[2], it was stated that these organs were really oviducts, or perhaps kidneys, and formed no part of the circulatory apparatus, but that the true blood-propelling organ was the pyriform vesicle, described by Professor HUXLEY as appended to the stomach. Further research has only tended to confirm the accuracy of these views, which now appear to be incontrovertible.

This vesicle or heart is present in all the *Brachiopoda* that I have examined, and when in an expanded state is of considerable size. In the articulated species it is appended to the middle line of the stomach, immediately behind the central gastro-parietal band, and projects freely into the perivisceral cavity, reaching down almost to the anterior margin of the oviducts: the free extremity is the larger one. When in this state, the walls, though rather thin, are firm, smooth, opake, and do not collapse; they are composed of two layers, the inner of which is distinctly muscular, the fibres running in various directions, but principally radiating from centres; the outer layer is delicate,

[1] Plate LXIV. fig. 3.

[2] Transactions of the Sections, p. 94.

transparent and homogeneous. The interior is entirely devoid of carneæ columnæ, and is perfectly smooth. When this organ is in a contracted state, its size is very much reduced, the surface is occasionally wrinkled a little, and the walls, of course, are much thickened.

This unilocular heart[1] in *W. australis* receives a large blood-channel or vessel[2] in front, which, running forward along the dorsal ridge of the stomach, within the membrane denominated mesentery, communicates on each side by several minute openings with the gastric lacunes, which are situated between the walls of the viscus and the membranous sheath. The anterior extremity[3] of this channel passes down the dorsal surface of the œsophagus, and dividing into two lateral trunks, opens at each side into a system of large lacunes placed around the root of the alimentary tube. These lacunes will be more particularly noticed afterwards. The channel is the afferent cardiac channel, or branchio-systemic vein.

A little behind the point where the heart receives this channel two aortic vessels pass off laterally, which are united at their origin across the median line. The two orifices communicating with those vessels are guarded by sphincture valves, resulting apparently from the protrusion inwards of the lining membrane; but from the minuteness of the parts I was unable to determine the exact structure of the valve. These two arterial trunks are adherent to the walls of the stomach, and, diverging backwards, each divides at the side of this viscus into two branches; one of which turns forward, and advancing to the lower margin of the gastro-parietal band runs along it, and coursing round the dorsal extremity of the posterior occlusor muscles reaches the inner wall of the outer pallial sinus, near to its commencement; it then bends forward, and entering the groove in the genital band glides along the edge of the suspending membranous fold, and is continued beyond the genital organ to the termination of the minutest ramifications of the sinus. A little in advance of the point where this artery leaves the gastro-parietal band it appears to give off a branch, which, running forward, goes to the margin of a membranous fold that stretches along the inner wall of the inner pallial sinuses; but this was not determined with sufficient accuracy. This fold is similar to those suspending the genitalia.

The other division of the artery passes backwards along the lateral margin of the ilio-parietal band, and then running across the under surface of the laminated portion of the oviduct next the median line, bifurcates. One of the branches passes inwards, the other outwards; the former, uniting with its fellow from the other side, runs along the free border of the mesenteric membrane, which extends from the dorsal aspect of the intestine, and passes into the base of the peduncle. This branch seems to supply that organ, but is much reduced in size before it reaches its destination. The branch, which passes outwards, continues adherent to the oviduct, and coursing over it, at the junction of the two portions, reaches the anterior wall of the perivisceral cavity; it then sinks downwards and advances to the loop of the genital band, where it again divides into

[1] Plates LII. fig. 10; LIV. fig. 1; LVI. fig. 1; LVII. figs. 1, 2.
[2] Plate LVI. figs. 5, 7. [3] Plate LVI. fig. 6.

two portions, which are continued into the outer and inner sinuses of the ventral pallial lobe, accompanying the genitalia in the manner above described, and in the same way extending to the terminal ramifications of the sinuses.

At the point where these latter genital arteries divide, there is situated a pyriform vesicle[1], which is apparently formed by the bulging out of the arterial wall; there is also a similar vesicle at the commencement of each of the dorsal genital arteries. There are consequently, in addition to the central vesicle or heart, four lateral vesicles, which seem to be accessory pulsatile organs. They are smaller than the heart, and their walls are more delicate. In some individuals there is also a small supplementary vesicle near to each of those of the ventral genital arteries; but whether or not these are abnormal it is impossible to say. They have been seen only in one or two instances; and the whole of these accessory vesicles are so delicate, that, unless the specimens be in the best possible condition, they are liable to disappear altogether. These supplementary vesicles may therefore be constant though seldom observed.

This is the condition of the central portion of the blood-system as determined in *W. australis*. In *W. cranium* no accessory pulsatile vesicles have been seen; but the heart and the afferent cardiac channel, or branchio-systemic vein, together with the dorsal and ventral pallial arteries, are all as above described[2]. In *T. caput-serpentis*[3] the heart is more decidedly pyriform than in the other species, and it is placed a little further back, the branchio-systemic vein passing for some distance down the stomach beyond the central gastro-parietal band. A single accessory pulsatile vesicle has been observed in connexion with one of the ventral genital arteries; others most probably exist.

The central portion of the blood-system in *Rhynchonella*[4] is arranged much as in the *Terebratulidæ*. The aorta, however, is not at once divided into two branches, but leaves the heart as a single trunk, which passes backwards as far as the pylorus before it bifurcates; and as the genitalia in this genus, as well as in *Terebratulina*, are much reticulated or convoluted, and as the suspending membrane follows the reticulations, there can be no doubt that the genital arteries in these two genera form an extensive open network. And when the genital sinuses give off branches to the pallial margin, arterial twigs are continued down them in the usual manner, as indicated by the continuation of the base of the genital membrane. When, however, no such branches exist, the artery appears to terminate in the plexus. The arteries have not been actually followed through the network, but they have been traced into the genitalia, so that there can be little doubt that they run the course above described. There is an accessory pulsatile vesicle attached to each dorsal genital artery as it enters the reproductive organ, and two in connexion with each of the ventral genital arteries; they are not large, and one is much smaller than the other, the smaller being undoubtedly equivalent to the supplementary ones in *W. australis*.

[1] Plates LVI. fig. 1; LXIII. figs. 3, 4.
[2] Plate LIV. fig. 2.
[3] Plate LIII. fig. 5.
[4] Plate LX. fig. 4; LXI. figs. 1, 2.

The existence of the genital arteries has not, I believe, been hitherto fully demonstrated. Professor OWEN, indeed, inferred their presence so long ago as 1833[1] from the ridges seen at the surface of the mantle accompanying the sinuses; in which ridges the membranes suspending the genitalia take their origin. This inference, however, has been controverted on the ground that the ridges only indicated the base of the suspending membrane. The presence of the genital artery is not, however, by any means difficult of proof. A cross section[2] of the genitalia divides the artery and exposes it to view. From its walls delicate membranes pass into the substance of the genital organ, which latter almost entirely encloses the artery. The true nature of the artery has been determined in this way as it passes from the heart, when in connexion with the parietal bands, and likewise in other places.

The central organs of circulation[3] have been observed in both *Lingula anatina* and *L. affinis*, and found to differ very slightly from those of the articulated species. The heart, which has been seen only in a state of contraction, is situated on the posterior slope of the stomach, exactly as in *Waldheimia*. It is pyriform, rather elongated, with the small end tapering gradually forward. The branchio-systemic vein originates in the dorsal mesenteric membrane, and communicates apparently through it, and two lateral membranes attached to the œsophagus, with a system of lacunes which surround that tube at its origin, much in the same way as in *Waldheimia*. The channel as it runs backwards passes between the divisions of the hepatic ducts, and is here rather enlarged; it soon assumes the form of a distinct, isolated vessel, and in this condition reaches the transverse dorsal ridge of the stomach from which the gastro-parietal bands originate, and at this point opens into the anterior apex of the heart. The aorta, as a single trunk, leaves the under surface of the large or posterior extremity of the organ, and in this respect differs from that of the articulated species; here the heart assumes more the character of a mere enlargement of the vessel. The aorta passes a considerable way down the straight portion of the intestine before it divides into two lateral stems. The heart and the aortic trunk are not closely adherent to the alimentary tube as in the other species, but are attached to the margin of a narrow membrane, which rises up from the external sheath of that viscus. The lateral stems pass outwards, and on reaching the ilio-parietal bands are again subdivided in the usual way, one branch running forward, the other backward in connexion with those bands. The former has been traced along the sides of the stomach as far as the gastro-parietal bands, the latter to the laminated portion of the oviducts; and thence there is apparently a branch running along the membrane, skirting the free border of these organs.

Besides these, there are, at each side, two arterial trunks[4], which penetrate the muscles. These, which may be termed respectively the internal and external, have not been traced throughout their entire course; but there can be little doubt that they are the continuations of the posterior branches of the lateral divisions of the aorta. The external

[1] Trans. Zool. Soc. vol. i. p. 154.

[2] Plate LVI. fig. 4.

[3] Plates LXIV. fig. 4; LXV. figs. 1, 3, 4; LXVI. fig. 1.

[4] Plate LXV. fig. 2.

ones have been followed right through the substance of the posterior adjustor muscles. That on the right side enters the posterior margin of the large single muscle, near to the point where it is in contact with the ilio-parietal band, and thence it goes directly to the opposite margin; it then becomes isolated and stretches forward between the dorsal and ventral ovaries of the same side, and, passing round the external surface of the anterior occlusors, turns inward, and a short way before it reaches the median line penetrates the lining membrane of the anterior wall, immediately below the ridge attached to the occlusor muscles[1]. It here apparently communicates with the lacunes situated between the two membranes of the parietes. The external trunk of the other side runs a similar course after passing through the two small posterior adjustors. These two trunks probably represent the ventral pallial or genital arteries of the articulated species. The internal are most likely connected with the external trunks; they pass from the anterior margins of the posterior adjustors, go directly through the central adjustors, and are lost amidst the fibres of the external adjustors, where they seem to branch.

These four lateral trunks have been described by Professor OWEN[2] as part of the nervous system, and indeed they bear a strong resemblance to nerves. But I can find no ganglia from which they originate, and the external ones undoubtedly pass into the anterior wall of the body as described: at this point, certainly, there are no ganglia nor anything like a nervous collar. The trunks themselves are composed of an inner and an outer tube; the latter is a continuation of the lining membrane of the perivisceral chamber; the inner is formed of a very delicate membrane, which, by the contraction of the outer tube, is thrown into longitudinal folds or wrinkles, having somewhat the appearance of nerve-tubes. These trunks, in fact, exactly resemble, in these respects, the free or isolated portion of the branchio-systemic vein[3], which has an outer envelope and a delicate internal tunic longitudinally wrinkled. So like are the two, that either might be figured or described for the other.

Having said so much with regard to the central organs, it will now be necessary to examine the peripheral portion of the blood-system. To do this we shall have to look to the parietes of the perivisceral chamber, and particularly to the lobes of the mantle, to the various membranous bands in connexion with the alimentary tube, and likewise to the brachial organs. In all these parts will be found the extensive system of lacunes, or blood-channels originally described by Professor HUXLEY[4].

First, with regard to the walls of the perivisceral chamber: these[5] are composed of two membranous layers, an outer and an inner, between which the lacunes are situated. The outer layer[6], of the dorsal and ventral walls, is made up of two very delicate membranes, the internal of which is pellucid and homogeneous; the external one is reticulated in a peculiar manner, as if it were formed of epithelial scales. The reticulations appear to correspond to the bases of the prismatic columns composing the shell. It is in this external membrane that the cæcal prolongations of the mantle originate, and the bases

[1] Plate LXVI. fig. 4. [2] Introduction to DAVIDSON's 'British Fossil Brachiopoda,' p. 12.
[3] Plate LXV. fig. 5. [4] *Op. cit.* p. 115. [5] Plate LIX. fig. 3. [6] Plate LIX. fig. 4.

of these enigmatical organs are distinctly visible rising up from the surface as short, delicate cylinders. And it may here be observed, that, contrary to expectation, they do not appear to penetrate even this external membrane, and consequently can have no communication with the lacunes or blood-channels lying between the two layers of the wall, or within those of the pallial lobes, as stated by Dr. CARPENTER[1]. This interesting point will be more particularly adverted to in the sequel. The inner layer of the wall is thin, transparent, and minutely granular, and is lined with a granular epithelium. Through these transparent layers the blood-channels, which lie between them, are seen, in well-preserved specimens, in all their details.

The anterior wall of the chamber has likewise its blood-channels between two layers, both of which are clothed with a granular epithelium. The lacunes of this portion of the tegumentary envelope form an open network, with the meshes elongated in the direction of the arms.

The pallial lobes[2] are each composed of two laminæ, an external and an internal one. The external lamina of both the dorsal and ventral lobes is a continuation of only the external layer of the upper and under walls of the body; the internal lamina is an expansion, in like manner, of the anterior wall. But those portions of the laminæ that form the walls of the great pallial sinuses are composed of both layers of the parietes. Hence the pallial lobe consists, above and below the sinuses, as well as in the spaces between them, of two layers, and the lacunes are situated everywhere between the layers, and intercommunicate. In other words, the pallial lobe may be described to be formed of a fold of the external layer of the parietes, the internal layer lining the great pallial sinuses throughout.

The external lamina of the mantle is formed of two membranes, exactly resembling those of the parietes of the body, the outer being reticulated, the inner transparent and homogeneous. The membrane of the internal lamina is of the same character as the latter; but it exhibits a few large, scattered, oval, granular cells. The pallial nerves are in connexion with this membrane, which is provided, on its external surface, with a stout, granular epithelium[3]. The layer lining the great pallial sinuses presents two different characters; that portion which lies next the shell is clear and homogeneous, that which rests on the lower wall or floor is slightly granular, and almost entirely composed of transverse muscular fibres. This layer is lined throughout with a granular epithelium.

The blood-channels or lacunes lying immediately below the external layer, and which may be called the outer pallial lacunes, are continuous with those in the parietes of the body; and throughout this extensive superficial system they have the same peculiar character. The channels are exceedingly wide, and in the spaces between the great pallial sinuses they are of considerable depth; in fact the whole of this system may be considered as one vast lacune, the walls of which coming together are united at certain

[1] Proceedings of the Royal Society, vol. vii. p. 34 (1854). [2] Plates LIX. fig. 1; LVIII. figs. 5, 7.
[3] Plate LXI. fig. 5.

points. These points of union are circular, and are arranged in groups of various forms and sizes, generally more or less rounded.

When the specimen is in good condition, this beautiful system of peripheral lacunes is well displayed, the channels or spaces being then for the most part filled with blood-corpuscles, which give to the lacunes an opake, yellowish hue, rendering them as distinct and sharp as though they had been injected. And as the circular points of union of the two walls are transparent, and are consequently liable to appear of a darkish tint, they show like spots on a light ground, not altogether unlike the markings on a leopard's skin. In other lights the whole has a beautiful lace-like delicacy. These lacunes occasionally assume a branched or dendritic character, particularly as they approach the margin of the mantle, where they become minute and run almost parallel to each other. These minute twigs pass on to the external margin of the lobe.

The inner lacunes, or those of the inner wall or floor of the great pallial sinuses, have a very different character; they resemble, however, considerably the lacunes in the anterior wall of the body with which they are in direct communication. They are in the form of numerous, narrow channels, which, anastomosing at various points, compose a network of very long, transverse meshes; thus most of the channels cross the direction of the sinuses and run parallel to each other. They communicate at the sides of the sinuses with the other system of pallial lacunes, and along the centre with that of the membrane suspending the genitalia. This membrane, like all the others, consists of two layers, and has its own system of anastomosing lacunes, which, on the one hand, is in connexion with the genital or pallial artery; and on the other, as just stated, with the inner pallial lacunes.

The lacunes in the floor of the inner sinuses of the dorsal lobe exhibit a slight modification; here they are not in regular transverse order, but form a pretty even network.

A few words more will complete the description of the pallial lobes. The margins[1] of these organs are complicated in their structure. Both the membranes of the external lamina seem to extend to the extreme edge of the shell, and the margin of the outer reticulated one is apparently continuous with the periostracum. A little within the edge of the shell the inner lamina is thickened and forms a fold, which is free in front and capable of extension and contraction. It is within this fold that the marginal setæ are developed; they originate in follicles, from which occasionally two or three setæ issue, though more frequently only one, and project from depressions in the margin. In connexion with the inner membrane of the external lamina, numerous muscular fibres are formed, which, increasing in number as they extend forward, pass into the marginal fold, and when in action will withdraw its free border; while a narrow muscular cord, which runs round immediately within the margin of the lobe, will probably control the lateral movements of the setæ. The setæ[2] themselves, which are placed a little apart from each other, taper gradually to exceedingly fine points, and are transparent, glisten-

[1] Plates LVIII. figs. 5, 6; LIX. fig. 1.

[2] Plate LVII. fig. 5.

ing, stiff and bristle-like; they are marked in a peculiar manner with transverse, dusky lines, perhaps indicating the progressive steps of growth.

The margin of the mantle has the same character in all the Brachiopods, and in all it is armed with setæ, which, however, vary considerably in length in the different species. In *W. cranium*[1] the edge of the marginal fold is entire, and the setæ are of various lengths, and rather minute and delicate; rarely more than two issue from the same follicle, generally only one. The setæ in *T. caput-serpentis*[2] are placed rather far apart from each other, and issue from the mantle at the points corresponding to the marginal crenulations of the shell; these crenulations give to the pallial membrane a scolloped appearance. The setæ are rather robust; the marginal fold is deep, and the follicles are of considerable length and rather wide, with their bases surrounded with glandular matter, forming a roundish, red-coloured spot at the end of each seta. Similar glandular matter is observed at the bases of the follicles in *W. australis*; but in that species it is elongated backwards. In *R. psittacea*[3] the setæ are slender, short and finely pointed; they vary in length, as they do indeed in all the species, and occasionally three or four issue out of one follicle. In all the species the setæ are marked with rather distant, transverse bars. In *Lingula*[4] the setæ are very long, and close-set, crowding the marginal fold, which is much thickened, and exceedingly deep, forming a wide border around the pallial lobe. They extend entirely round the dorsal lobe, and in the ventral one are interrupted only for a short space behind, at the point where the peduncle is attached to it. They are marked with numerous, rather close, transverse bars, from every one of which a narrow edge projects forward encircling the setæ, giving them the appearance of being jointed, and, as VOGT[5] observes, rendering them very like the stems of an Equisetum.

Some time ago Professor SCHMIDT[6] discovered calcareous spicula or plates in the mantle, arms, and cirri of *T. caput-serpentis*; and more recently Mr. WOODWARD[7] exhibited, at a meeting of the Zoological Society, not only spicula in the pallial lobe of this species, but also in that of *Terebratula vitrea* and of *Megerlia truncata*. This gentleman has also found indications of imbedded calcareous matter in the mantle of *Argiope decollata* and *Crania*.

In *T. caput-serpentis*[8] the spicula are large, much branched, colourless, glass-like and pellucid, somewhat like the antlers of a Deer, only the branches are all in the same plane, and are flattened or depressed a little. They are, however, frequently much complicated, forming a central network, with irregular, radiating branches; in others, again, the branches pass from a simple perforate centre. These spicula lie in the outer layer of the inner lamina, and are crowded to such a degree, that the tips of the branches are almost in contact; thus forming an extensive, though incomplete network of calcareous

[1] Plate LIII. figs. 3, 4. [2] Plates LIII. figs. 1, 2; LVII. figs. 6, 7. [3] Plate LX. figs. 1, 2, 3.
[4] Plates LXIV. figs. 1, 2; LVII. figs. 8, 9. [5] *Op cit.*
[6] DAVIDSON, Ann. and Mag. of Nat. Hist. vol. xvi. p. 440, 1855.
[7] Proceedings of Zool. Soc. 1856, p. 368. [8] Plates LII. figs. 6, 7, 8; LX. fig. 12.

matter over the trunks of the great pallial sinuses. Elsewhere they are sparingly distributed, except towards the margin of the lobes, where they are rather numerous.

In *Megerlia truncata*[1] the spicula have much the same character, but the branches are so much flattened or spread out, that they become extensively fused, so as to form plates of irregular forms; and as the margins of these plates are in contact, the whole compose a tolerably compact shield with sharply defined borders, corresponding very closely in form to the pallial sinuses, to which, no doubt, they give protection, resisting the pressure of the external fluid.

In both species the spicula are continued from the mantle into the arms, where the branches become interwoven so as to compose a sort of sponge-like tissue of calcareous matter, which firmly supports these organs. In the cirri the spicula retain their branched character, and curving round them enclose their lower portions in an open network. Were these species fossilized, it is quite possible that their arms might be so preserved as to give the appearance of their having been sustained by some apophysary apparatus; and in that case the roots of the cirri would be found projecting much in the same way as the salient spines or processes on the calcareous spirals of the fossil *Spiriferina rostrata*; and perhaps these spines were formed by similar imbedded spicula. No spicula are found in *Waldheimia*, *Rhynchonella*, or *Lingula*.

From the description already given of the peripheral lacunes, it would seem that the walls of the body, and the laminæ of the pallial lobes, present one great system of blood-channels or lacunes, the various parts of which freely communicate with each other. There still remains, however, to be examined the peripheral system in the membranous bands of the perivisceral chamber, and in the brachial apparatus; but in the first place it will be well to refer to the sheath of the alimentary tube. As before stated, this tube is encased from end to end in a close-fitting membranous sheath; between which and the proper walls of the tube, the blood, which nourishes this viscus, undoubtedly flows in lacunes; but from the opacity of the parts the exact character of the channels could not be determined. Blood-corpuscles, however, were found strewed about between the sheath and the walls of the organ, apparently occupying a network of channels. Towards the root of the œsophagus, where the sheath is not so much constricted, large blood-channels or lacunes[2] are situated between it and the walls of the tube. These may be denominated the great œsophageal lacunes; while those of the other portion of the alimentary tube may be named the visceral lacunes, as they seem to form part of a system which extends to the liver and heart.

Now, all the bands which pass from the alimentary tube to the parietes are, in fact, duplicatures of this sheath, and accordingly they are found to be composed of two layers, each with its proper epithelial covering. The layers are exceedingly delicate, transparent, and homogeneous; and between them are situated numerous blood-lacunes, which are narrow anastomosing channels. Those in the gastro-parietal bands run[3], for the most part, in the direction of their length, and communicate at one extremity with the visceral

[1] Plates LII. fig. 9; LIII. figs. 6, 7. [2] Plate LV. fig. 4. [3] Plate LVI. fig. 8.

lacunes, and at the other with the posterior portion of the outer pallial system of the dorsal lobe. The lacunes in the ilio-parietal bands connect the lower portion of the visceral lacunes with the posterior portion of the outer pallial system of the ventral lobe. The mesenteric lacunes[1] have the same character as those in the other bands, and run principally in a longitudinal direction, and maintain a communication between the visceral lacunes and those of the walls of the body.

The liver has no doubt its proper system of blood-channels communicating with those of the other viscera; and though they have not been demonstrated, it appears pretty certain that they lie between the walls of the numerous ramifications of this viscus and a membranous envelope, an expansion of the sheath of the alimentary tube, which has the appearance of being reflected from the stomach upon the hepatic ducts, and is, there can be little doubt, continued throughout its various subdivisions.

The muscles seem likewise to be sheathed in a membrane which apparently penetrates the interstices between the bundles of fibres, so strikingly displayed at their enlarged extremities. The blood, which goes to nourish these organs, will, for the most part, pass from the lacunes of the parietes to within the sheaths, and has its course defined in lacunary channels, which can be easily observed on making a transverse section of the occlusor muscles. The occlusors being in connexion with the mesenteric membrane and the anterior parietes its blood-channels, will be also in direct communication with the visceral system. It would then appear that the visceral system of lacunes is connected with the parietal and pallial systems through the instrumentality of the several parietal bands; and what may be denominated the muscular lacunary systems are probably in communication with all three.

The blood-system of the brachial apparatus next claims attention. This is beautifully developed, and presents considerable variety in the character of the several plexuses of which it is composed. The walls of the great canal, the ridge supporting the cirri, the membranes that unite the upper and lower members of the loop, that which connects the spirals, and those which form the small canal or channel at the base of the cirri, as well as that forming the sheath of the apophysary support,—all have their system of lacunes which intercommunicate and compose the brachial system.

The processes of the inner lamina of the mantle which pass along the lateral brachial folds, and within the margins of which the calcareous support is developed, are formed of two layers; and the network of lacunes of the inner pallial system is continued between them. This continuation of these lacunes is in connexion with the brachial system. The lacunes in the walls of the great brachial canal also communicate with those of the same inner pallial system. There is likewise a small canal which runs along the arm from base to point immediately below the brachial fold. The blood-channels of the anterior wall of the body communicate with the extremity of this conduit, and as it passes along it pours its contents into the plexus of the great brachial canal. This, which may be denominated the afferent brachial canal, was not very

[1] Plate LIV. fig. 8.

distinctly observed in *W. australis*, but is sufficiently conspicuous in *R. psittacea*[1], in which it was traced from the junction of the arms to a considerable distance along them, charged with blood-corpuscles. In this species the channels of the anterior wall of the body run in the direction of these canals.

The walls of the great brachial canal[2], like those of the body, are composed of two layers, the inner displaying muscular fibres, as already stated, the outer being homogeneous: both are clothed with an epithelium. That lining the canal[3] is distinctly formed of irregular polygonal scales with scattered granules. The external epithelium is stouter than the other, and is more crowded with granules. In the space between the two layers there are numerous lacunes resembling those in the anterior parietes; but they form pretty regular parallel channels of limited width, which occasionally anastomosing run diagonally round the canal. These channels take their origin in a minute plexus situated directly above the membrane connecting the spirals. The afferent canal runs along at the other side of or below this membrane, and the network of channels excavated in its substance, which is thick and of a semi-cartilaginous appearance, becomes the medium of communication between the afferent canal and the minute plexus just mentioned. At the points of communication the channels in the membrane form minute networks. Towards the interior of its substance the meshes are much enlarged. After winding round the canal, the brachial blood-channels are again lost in a similar minute plexus situated at the base of the semi-cartilaginous ridge supporting the cirri. This plexus is in connexion with another system permeating the substance of the ridge, which conducts the blood through amidst the roots of the cirri to a peculiar network of channels, in like manner excavated in the substance of the ridge next the brachial fold. This, the great brachial plexus[4], is supplied with central trunks which give off branches; some of these pass towards the base of the ridge, and, anastomosing as they go, result in a regular series of transverse channels, which, on reaching the small canal running along at the bases of the cirri, attain proper walls, and as distinct vessels[5] pass through the wall of this canal, and, turning in the direction of the cirri, enter the bases of these organs in regular parallel order. These vessels are the afferent brachial arteries.

The small canal at the bases of the cirri is situated within the large brachial canal, and is apparently formed by a duplicature of the lining membrane of the latter. The septum, thus dividing the two canals, is composed in the usual way of two layers, and is provided with its system of anastomosing channels which open into those of the great canal. The small one is the efferent brachial canal. The bases of the cirri, which are situated in a groove, open freely into it in a double series. The cirri themselves[6] are tubular with their apices rounded and imperforate; they are a little flattened at the approximate sides, and are apparently lined throughout by the continuation of a delicate granular epithelium which coats the efferent canal. Towards the base the walls are stout, and have a ridged, horny character; they gradually become attenuated

[1] Plate LX. fig. 10.
[2] Plate LIX. fig. 2.
[3] Plate LXI. fig. 6.
[4] Plate LVIII. fig. 1.
[5] Plate LVIII. fig. 3.
[6] Plate LVIII. fig. 4.

upwards, and are very delicate for about one-third of their length from the apices, their extremities being frequently curled in spirit-specimens: this portion is undoubtedly to some extent contractile. The surface is coated with a rather thick, opake, granular epithelium, which probably sustains vibratile cilia. Upon the removal of this, the walls becoming transparent exhibit double transverse lines; and an internal ridge is seen to extend up one side from the base almost to the apex. Externally there is a deep, membranous keel, or wing, projecting apparently from the same side. The bases of the cirri sink, for some depth, into the substance of the supporting ridge, and open into the efferent canal through gradually expanding mouths. The afferent brachial arteries, originating in the great brachial plexus, enter these expanded orifices, and pass up the interior of the cirri attached to the side next the brachial fold apparently in connexion with the internal ridge; they advance to the apices, where they seem to terminate in open mouths; they do not occupy more than about half the calibre of the channel. The blood therefore poured out of the vessels within the apices of the cirri will find its way down them to the efferent canal of each arm. These canals running backwards to the sides of the œsophagus terminate there, each in a considerable sinus, the efferent brachial sinuses[1], which are somewhat wider than the root of the œsophageal tube, and are of a semi-lunar form, each bearing on its wall a peculiar opake, flattened tubercle; the sinuses pass backward beyond the tube, and are separated behind by the insertion of another large sinus[2], which lies within the layers of the mesenteric membrane, and abuts against the under side of the alimentary tube. The efferent brachial sinuses communicate with this median sinus by numerous apertures, as they do also with the system of large lacunes previously pointed out as being placed round the commencement of the œsophagus, and into which we have seen that the branchio-systemic vein[3], extending along the dorsal ridge of the stomach, opens by two branches.

Traces of the peripheral system have been found in the other species examined; but in none of them has it been so fully observed as in *W. australis*, and in this form it is frequently very indistinct, owing to the condition of the specimens. In *R. psittacea* the vessels leading to the cirri from the great brachial plexus are arranged exactly as in *Waldheimia*; and very distinct indications of the lacunary channels have been observed in the other parts of the economy of this species.

The peripheral lacunes have not been examined in *Lingula*, with the exception of the outer pallial system[4], which is composed of parallel channels freely communicating with each other, and which to some extent are arranged conformably to the great pallial sinuses. It cannot be supposed, however, that in the peripheral system any important difference exists, as it has been shown that in this form the central organs are similar to those in *Waldheimia*. The efferent brachial canal[5] is nevertheless somewhat modified. In *Lingula* it is not formed, as it were, by a septum cutting off a portion of the great brachial canal, but it is excavated in the substance of the semi-cartilaginous ridge at the

[1] Plate LV. fig. 4. [2] Plate LVII. fig. 2. [3] Plate LVI. fig. 6.
[4] Plate LXVI. fig. 5. [5] Plate LXV. fig. 8.

base of the brachial fold. This canal, which is of no great size, is close to the roots of the cirri, which are somewhat expanded, and open into it at the side; it also communicates with cellular interspaces situated in the thickness of the brachial fold. Further than this I have not succeeded in determining the anatomy of these parts, owing to their opacity and minuteness.

Having now gone over all that I have been able to ascertain with respect to the central and peripheral portions of the circulatory apparatus, and having also examined the lacunes and blood-canals of the brachial organs, it will not be difficult to follow the flow of the blood throughout its entire course in *Waldheimia*; and as it is in it, so will it be, in all probability, in all other Brachiopods.

It has been shown that the heart[1] is a simple, unilocular, pyriform vesicle, suspended from the dorsal aspect of the stomach, and projecting freely into the perivisceral chamber; that there is neither auricle nor pericardium, unless the membrane which closely invests it can be so called; that it is hardly more complex in structure than the pulsatile vessel of the Tunicata; and that in *Lingula*, indeed, it scarcely at all differs from the heart of those lowly organized mollusks. This vesicle, or heart, propels the blood through four arterial trunks or channels to the reproductive organs and mantle, and probably also to the alimentary tube, and is apparently assisted by four or more pulsatile vesicles in connexion with these principal trunks. The blood thus conveyed by the genital or pallial arteries will escape by the lacunes in the membranes suspending the genitalia, into the plexus in the floor of the great pallial sinuses. Thence it will find its way into the outer lacunary system of the pallial lobes, and into that of the dorsal and ventral walls of the body, as well as into the lacunes of the anterior parietes. Having saturated all these parts of the peripheral system, it will divide itself into two currents, one of which will set backwards in the direction of the membranous bands connecting the alimentary tube to the parietes, and will flow through their channels into the system of visceral lacunes, which encircle the alimentary canal within the sheath, and which probably carry blood to the liver. This current will also supply the lacunes nourishing the muscles. The blood thus directed will reach the branchio-systemic vein, either by the great œsophageal lacunes, or through the foramina which penetrate the sides of the channel as it runs along the dorsal ridge of the stomach.

The other blood-current will set forward in the direction of the base of the arms, and some of it will pass into these organs through their general system of lacunes; but the principal portion will be carried by the afferent brachial canal to the extensive plexus of lacunes in those parts, and will circulate, in the manner before pointed out, within the walls of the great brachial canal. The blood will then be drawn up one side of the cirri through the vessels,—the afferent brachial arteries,—originating in the great brachial plexus, and returning down the other, will be poured into the efferent brachial canal, and thus reach the lateral efferent sinuses at the root of the œsophagus. Thence it will

[1] Plate LXIII. fig. 1.

enter the great œsophageal lacunes, and there meeting with the other current of returning blood from the visceral lacunes, will be carried to the heart by the branchio-systemic vein along the dorsal side of the stomach.

Thus it is perceived that the blood finds its way back to the central organ in a mixed condition. That which is conveyed by the gastro-parietal and other bands will be imperfectly aërated, having only flowed through the pallial membranes, which must be looked upon as but accessory oxygenating agents. The arms undoubtedly perform the office of gills, and are true respiratory organs. The blood which circulates through them will consequently be returned in a perfectly aërated condition, to be mixed, however, with that in a less pure state from the visceral lacunes before it enters the heart. This mixed state of the blood is not by any means peculiar to these animals, for it obtains in many of even the higher mollusks.

To prove that the brachial organs subserve the function of gills, as well as that of sustentation, it is only necessary to refer to the manner in which the blood circles round the arms and is carried to the cirri; but more particularly to its circulating through these latter organs, and to its return direct from them to the heart. There can be no doubt that the cirri are provided with vibratile cilia, and indeed this fact seems to be established by the observations of Mr. BARRETT[1]; and a considerable portion of their extremities is sufficiently delicate to admit of the blood being aërated through their walls. The inner lamina of the mantle, and more particularly that portion of it forming the floor of the great pallial sinuses, will undoubtedly assist in purifying the blood; but like the mantle of many of the Nudibranchs, it can only play a secondary part. This may fairly be inferred from the distribution of the blood-channels within the lamina. In *T. caput-serpentis*[2], however, this portion of the mantle is so filled with calcareous spicula, that in this instance it must, even in this secondary capacity, have its efficiency much impaired; and in *Megerlia truncata*[3] the floor or inner wall of the trunks of the great sinuses is completely filled with spicula to such an extent, that the membrane seems entirely displaced.

It is generally asserted that the mantle in *Lingula* has assumed the character of a rudimentary gill; and in this genus, indeed, it perhaps attains its highest development as an accessory breathing organ. I find, however, nothing agreeing to the so-called vascular loops of Baron CUVIER[4] and Professor OWEN[5]. The mantle[6] does not appear to differ at all from that of the articulated Brachiopods, except that the inner walls of the pallial sinuses are bulged out, forming, as it were, transverse or radiating plaits: there are, however, no branchial loops; but the surface over which the inner lacunes are distributed being thus increased, the lobes of the mantle in *Lingula* may, to this extent, be considered specialized breathing organs. Nevertheless there is no reason for supposing any modification in the internal arrangement of the blood-channels, that there

[1] *Op. cit.* [2] Plate LII. fig. 6. [3] Plate LII. fig. 9. [4] *Op. cit.* p. 5.
[5] Trans. Zool. Soc. vol. i. p. 157. pl. 23. fig. 16. [6] Plates LXIV. fig. 3; LXVI. fig. 5.

are any afferent and efferent trunks leading directly to and from these so-called rudimentary gills. In fact, in most of the Brachiopods the inner lamina of the pallial sinuses is more or less bulged out; it only happens that in *L. anatina* the bulging is to a greater extent, and the sinuses, being parallel, assume a plaited or laminated character. In *L. affinis* the sinuses are branched[1], and consequently the gill-like structure is not by any means so distinct, though the walls of the sinuses are much inflated[2].

This modification of the inner lamina of the mantle is much of the nature of those various modes of increase of surface observed in the pallial fringes and processes of various mollusks, all of which, there can be little doubt, assist in aërating the blood.

The great extent of brachial organ is also worthy of remark. In *R. psittacea*, for instance, the arms, when stretched out, are 4½ inches long, being upwards of four times the length of the shell; and they give support to about 3000 cirri. To account for the enormous development of these organs, it is necessary to look to something beyond the sustentation of the animal; and the conclusion seems a natural one, that they are destined for the oxygenation of the blood. Analogy would also lead to the same conclusion, whether we look to the *Polyzoa*, to the *Tunicata*, or to the *Lamellibranchiata*.

With regard to the cæcal prolongations of the mantle, it has already been stated that they can scarcely have anything to do with respiration, as has been supposed. Such an opinion rests upon the assumption that they open into the outer pallial lacunes. Now, so far as my observations go, they have no communication at all with them: on the contrary, they seem to originate in the external reticulated layer of the mantle, and do not even penetrate it; the reticulations can be seen passing across their bases[3]. But should they actually perforate this layer, there is still the homogeneous layer separating them from the pallial lacunes. Such is the result of a very attentive examination of this point; and yet it is with some hesitation that it is enunciated, as Dr. Carpenter, than whom no one is more able to determine this question, entertains the contrary opinion. He appears to have examined the membranes whilst in connexion with the shell; my observations were made after the shell had been reduced by acid. The difference of our results may perhaps arise from the different modes of investigation; at all events, the subject is worthy of further attention.

It must, however, be acknowledged that the corpuscles, almost always found in these cæca, strongly resemble blood-corpuscles; they are of the same colour and form; but in one instance they had undergone a very marked change as to the former character. On placing a fine individual of *W. australis* in acid as soon as the periostracum was removed, the shell was observed to be marked with large patches of dark purplish brown. These patches continued to increase in intensity until the shell was entirely reduced, when the coloration was found to arise from the contents of the pallial cæca, which were made up of the so-called blood-corpuscles, all of which were of a rich purple-brown colour. In other parts, where no coloration existed, the contents of the cæca had their usual appearance, being of a yellowish hue.

[1] Plate LXVI. figs. 1, 2, 3. [2] Note 3, p. 851. [3] Plate LIX. fig. 4.

It is not easy to explain this phenomenon on the supposition that the corpuscles are really blood-globules; but the difficulty would at once disappear if it were assumed that some local disease had produced this abnormal condition in the contents of the cæca; in which case it must be concluded that the corpuscles form an integral part of the cæca themselves, or rather that they are permanently placed within these organs, and do not flow through them, as they must do were the cæca connected with respiration.

It is also a significant fact, that the *Terebratulidæ* are liable to be covered with extraneous matter. Several of the individuals of *W. australis* that have passed through my hands were extensively encrusted with zoophytic and other parasitic growths; and one or two of *T. caput-serpentis* had both valves entirely enveloped in a dense downy coat of some species of sponge. This appears, from what FORBES and HANLEY state in their 'British Mollusca,' to be frequently the case, and to have gained for the specimens so clothed the specific name of *pubescens*. Were the cæca respiratory organs, even in a secondary capacity, this would hardly be the case.

The best mode of investigating these organs[1] is to dissolve the shell, and then they are exposed, in various stages of growth, adhering to the margin of the mantle. They are arranged in rows, and are cylindrical, with the distal extremity obtusely rounded, and are pedunculated from the first; the peduncle is long and narrow; the cæca at the extreme edge are small, but rapidly increase in size backward; the terminal or enlarged portion is almost constantly stuffed full with the so-called blood-corpuscles. When observed in this way, these organs have very much the character of secerning follicles, but what function they really subserve is difficult to determine; it may be that they have something to do with the growth and reparation of the shell, though it is not easy to understand how. They are probably, as suggested by Professor HUXLEY[2], the homological representatives of the vascular processes that penetrate the test of the Ascidian; and if so, it would seem likely that they have lost much of their functional importance; and in fact their entire absence in forms closely allied to those in which they are highly developed, augurs that they are not of any high functional signification. It may therefore be here, as it is in the *Ascidiæ*, that they maintain a vitality in the external covering or shell; low, indeed, in comparison to that of the test of the latter, but sufficient, perhaps, to repair the shell should it be fractured; and as the Brachiopods do not, to any great extent, thicken their shells by successive internal layers, some such provision appears necessary for the purpose.

The reticulated membrane, which is closely adherent to the homogeneous layer beneath, and in which the cæca originate, has very much the character of an epithelial layer. It is therefore not unlikely that they may be productions merely of the epithelium.

From the foregoing account of the circulatory apparatus, it is evident that the perivisceral chamber, and its various so-called vascular ramifications in the mantle, are not

[1] Plate LVIII. fig. 8.

[2] Introduction to DAVIDSON's 'British Fossil Brachiopoda,' p. 30.

connected with the blood-system. This is no doubt a startling fact. I commenced the present investigation fully imbued with the opinion that these parts were blood-reservoirs and channels, and I only relinquished it when it became no longer tenable. Step by step the points relied on had to be abandoned, until at length the full conviction was arrived at, that I had been seeking to establish a fallacy. I have been unable to discover any communication between the true blood-system and the pseudo-vascular ramifications in the mantle, or the perivisceral chamber. Injections were thrown into this chamber, but none of the fluid found its way into any part of the lacunary system. The pallial lobes were removed, and the great pallial sinuses distended to their fullest capacity, with exactly the same result; and it was not until great pressure was applied, and the tissues ruptured, that a little of the injected matter was extravasated into the peripheral lacunes. The perivisceral chamber, then, and all its various ramifications, are in no way connected with the true blood-system. They must have some other peculiar and important office to serve in the economy of the animal. What is this office? This shall be discussed by and by, and in the meantime it is necessary to revert to the structure of the peripheral lacunes themselves.

These, which answer to the veins and capillaries of the higher animals, are of a very peculiar character. They are for the most part, as we have seen, placed between two membranous layers, or between one such layer and the walls of the viscera. In the former case they can be readily examined, and are found, how various soever their forms may be, to be constructed in the same manner. With regard to those of the outer system of the mantle, it has been shown that they are nothing more than intercommunicating spaces left between two membranes, which are only partially united. In this way they are all formed, but in some the channels take a linear disposition, and compose more or less open networks of various degrees of minuteness, always sharply defined. In well-preserved specimens the lacunes are perfectly distinct, and are generally well charged with blood-corpuscles, which are liable to adhere to each other, forming oval pellets[1]. These channels, moreover, do not appear to be entirely free, but to be encumbered with cellular tissue; so that, when one of the membranes is removed, the coagulated blood remains adherent to the other, retaining the form of the channels in all their distinctness[2].

It has been pointed out that the alimentary canal is encased within a sheath forming the system of visceral lacunes, and that it apparently coats the liver, following all its minute subdivisions. Now, it is the continuation of this sheath, reflected upon the walls of the perivisceral chamber, that forms the lining membrane or inner layer between which and the true walls of the body the parietal lacunes are situated. And moreover it is pretty evident that this membrane also sheaths the muscles, and is continued throughout the great pallial sinuses, enclosing the genitalia within a fold. The various bands, too, passing from the sheath of the alimentary tube to the parietes are

[1] Plate LX. fig. 11.

[2] Plate LIX. fig. 3.

duplicatures of this membrane. Thus it appears that the various systems of peripheral lacunes may be considered as one great, continuous blood-reservoir, notwithstanding the multiplicity of its parts. Those of the brachial apparatus may perhaps be an exception to this, and form, to some extent, a distinct system, though they undoubtedly communicate with the lacunes of the parietes. This distinctness, however, is probably more apparent than real, and the great canals of the arms are perhaps only prolongations of the general cavity, though they are cut off from it by a delicate membrane. The two membranes composing the walls of these canals would seem to indicate this.

It is also worthy of remark, that the channels which have been denominated arteries soon lose the appearance of having proper walls. At their origin in the *Terebratulidæ*, they seem to be within the visceral sheath, bulging it out; and as they pass over the parietal bands, they have a peculiar texture and are somewhat different in colour. After reaching the genitalia their character is a little changed, they having assumed the appearance of being formed by the membrane suspending these organs, as if they had become mere channels left within the two layers composing it. This is also the character of the branchio-systemic vein, which seems to be nothing more than a space left between the layers of the mesenteric membrane, though, as it approaches the heart, it has probably proper walls. The efferent brachial canal has all the appearance of being formed by a duplicature of the lining membrane of the great brachial canal; but in *Lingula* it is excavated in the substance of the brachial ridge. There can be little doubt, however, that the vessels which have been termed afferent brachial arteries, those vessels which drain the great brachial plexus and pass up the cirri, have true walls.

This latter fact seems to favour the opinion that the lacunes themselves may have proper walls, and that all these channels are connected from end to end with the central organs by continuity of tissue; to favour, in fact, JOHN HUNTER'S views with regard to the blood-sinuses in the lower animals. I have failed, however, to discover any such continuity of tissue demanded by the hypothesis of our great anatomist. If such had any other than a hypothetical existence, it ought, one would think, to be demonstrable in the *Terebratulidæ*; for perhaps in no other molluscous animal are the peripheral blood-channels so beautifully displayed, and, from the peculiarity of their arrangement, so easily submitted to examination by even the highest powers of the microscope. The tissues are very transparent, and the blood-channels or lacunes most distinctly defined; the only problem being, are these latter lined with a membrane? They contain apparently cellular tissue; does the membrane of continuity thread the meshes of this tissue? or may the tissue itself turn out to be the required walls? These questions must for the present remain unanswered, and in the meantime it would appear best to denominate the channels lacunes, as has been done throughout this communication, for to use the term sinus would be to imply that they had true or proper walls; a matter, to say the least, of extreme doubt.

Perivisceral Chamber.

The great cavity[1] placed close to the hinge of the valves, in which the viscera are lodged, is limited above and below by the dorsal and ventral walls of the body, and in front by the inflection of the inner lamina of the pallial lobes. There are no openings leading into this chamber, except those of the oviducts, which have been already sufficiently described. The œsophagus penetrates the anterior wall; and in the *Terebratulidæ* there are two anterior prolongations of the cavity extending to the extremity of the lateral brachial loops. These prolongations, the brachial pouches, are formed, as before explained, by processes of the inner lamina of the mantle. In *Rhynchonella* there are no such prolongations. The great pallial or genital sinuses open freely into this chamber; they are merely continuations of it, and lie between the two laminæ of the lobes. In *W. australis*[2] there are four of these sinuses in each lobe, two on each side of the median line; they extend from the front of the chamber to the anterior border of the lobe. The external ones are very wide, and give off eight or nine branches from their outer margins, which dividing three or four times dichotomously, result in small twigs, that appear to terminate in a vessel running round the edge of the lobe just within the roots of the marginal setæ; they seem, however, sometimes to end in blind sacs before they reach this vessel. The inner sinuses are comparatively narrow, and on approaching the anterior border of the lobe divide into two short branches similar to those already described. The inner dorsal sinuses, which never contain genital bands, are smaller than the inner ventral ones, and taper gradually forward.

The circumpallial vessels of the two lobes were not very satisfactorily determined; they appear, however, to communicate with the terminal twigs of the great sinuses, to unite posteriorly at the junction of the lobes, and as two lateral trunks to open into the perivisceral cavity, one at each side of the peduncle immediately behind the cardinal process.

There is no modification to note in the perivisceral chamber in any of the *Terebratulidæ* that I have had an opportunity of examining. The pallial sinuses, however, vary in the several species. Thus in *W. cranium*[3], though there are still four such sinuses in each lobe, the trunks are proportionately smaller, and more nearly of a size; the branches are fewer and more attenuated, but, as in the other species, divided dichotomously twice or thrice, without any very marked symmetry.

In *T. caput-serpentis*[4] the four trunks may still be recognized; but a considerable change, as previously noted, has taken place. Here the trunks are fused so as to form in each lobe two large, lateral semi-lunar sinuses, in which the genitalia are placed. The external margins of these sinuses give off numerous, rather delicate branches, which dividing dichotomously run to the pallial margin; the branches next the middle line, which correspond to the inner sinuses, pass off from their internal margins, and divide once or twice.

[1] Plates LII. fig. 10; LVII. figs. 1, 2; LXI. figs. 1, 2.
[2] Plates LII. figs. 1, 2; LIX. fig. 1.
[3] Plate LIII. figs. 3, 4.
[4] Plate LIII. figs. 1, 2.

In *Rhynchonella*[1] a further change is perceptible; there are, however, as in the last species, four genital sinuses of much the same character; but the two in the dorsal lobe give off no branches. These would seem to correspond to the outer sinuses in *Waldheimia*. The inner ones are represented by two trunks which come from the perivisceral chamber, one on each side of the median line, between the expanded bases of the occlusor muscles; they diverge, and turning outwards and backwards circle round a little in advance of the anterior margin of the genital sinuses, giving off numerous branches. The branches divide three or four times, and as the ultimate twigs approach the marginal vessel they invariably bifurcate. The sinuses of the ventral lobe have their anterior margins next the median line prolonged each into a stout trunk, which soon divides into two portions, one of which advancing inclines inwards, the other directed outwards and backwards turns round a little in front of the genitalia. These two portions give off several branches to the pallial margin similar to those of the other lobe.

The perivisceral chamber of *Lingula anatina*[2], though constructed precisely as in the other Brachiopods, is considerably modified in form. It is much larger than usual, extending forward nearly half the length of the shell; and is depressed and elongated, with the dorsal and ventral walls very delicate, transparent and membranous; the lateral ones strong, opake, and muscular. The latter are firmly attached by their margins to the valves, defining with great distinctness the exact boundaries of the chamber. The anterior wall slopes forward towards the dorsal valve to accommodate the advanced position of the occlusor muscles; thus forming a sort of anterior pouch or recess, through the centre of which the œsophagus passes.

There are four pallial sinuses, two in each lobe, which open into the cavity in front, one at each side between the attachments of the posterior occlusors and the adjustor muscles. These sinuses pass forward, converging until at the anterior margin of the lobe they almost meet on the median line. Long, however, before they reach their terminations they suddenly contract, and lose the character of trunks. They give off from their outer margins numerous close-set, simple, parallel branches, which vary in size, generally alternating, large and small, and pass towards the circumference in a radiating manner. On reaching the thickened border of the mantle they abruptly contract[3], and, as much-attenuated twigs, terminate apparently in blind sacs a little within the free margin. These branches are much bulged out into the pallial chamber, and when not distended with fluid assume the form of plaits, giving to the mantle a regular laminated appearance. Small branches also proceed from the inner margin of the main trunks, which for the most part pass inwards and backwards, and end in cæcal extremities. There is also a posterior branch which springs from the root of the great trunk and turns immediately backwards, runs along the lateral expansion of the mantle outside the adjustor muscles, and terminates behind the divaricator muscle, giving off, all the way from either

[1] Plate LX. figs. 1, 2, 3.
[2] Plates LXIV. figs, 1, 2, 4, 5; LXV. figs. 1, 3.
[3] Plate LXIV. fig. 3.

side, numerous irregular ramuscules. The outer ones stretch to the free edge of the pallial border, the inner extend almost to the lateral wall of the body.

In *L. affinis* the branches of the pallial sinuses[1] taper gradually and are a good deal subdivided, and though considerably bulged out do not assume the appearance of laminæ. The two main trunks of the ventral lobe turn suddenly inwards, and meet on the median line, forming, as it were, an arch from which the branches radiate to the pallial border.

The branches of the pallial sinuses are frequently choked up with a reddish-brown matter, which on examination with a microscope is found to be entirely composed of large, roundish, scale-like bodies, no doubt from the epithelial lining of the chamber and its ramifications, which lining in all the Brachiopods is exceedingly deciduous, and rarely observed in its natural position. In the *Terebratulidæ* the sinuses are also not unfrequently clogged with matter, which has been taken for coagulated blood; but on attentive inspection it is found to be made up of similar epithelial scales.

It has been already stated that this complicated chamber is lined throughout with a membrane as well as all the ramifications of the pallial sinuses; and that folds of this membrane form the various bands which pass from the parietes of the body to the visceral sheath, which is itself apparently an involution of the same membrane. The muscles are likewise sheathed by it. To arrive at an understanding of the function of this chamber, so formed, it is necessary in the first place to determine the nature of this lining membrane. Where shall we look for its homologue? Does it form an essential element in molluscan organization? For answers to these important questions I am indebted to Professor HUXLEY, a gentleman from whom I have derived much and important information in connexion with the subject of this paper, and who has with the utmost candour and liberality communicated to me his views on these very interesting points,—interesting, for they relate to all that is most anomalous in the anatomy of these animals, consequently to that which particularly demands our attention.

Before these questions can be solved it is necessary to refer to the *Ascidiæ*, which rank with the lowest organized Mollusks. These animals are provided with several envelopes or tunics; in the first place there is the external covering or test; next the lining membrane or outer tunic; and within it the third tunic enclosing the space termed the atrium by Professor HUXLEY[2]. The space thus circumscribed communicates externally through the excurrent tube; and the blood flows between the outer tunic on the one hand, and the third tunic and the intestine on the other.

Now in the Brachiopods we have the shell which is equal to the test of the Ascidian; then comes the mantle in the place of the outer tunic; but there is nothing to represent the third tunic, unless the lining membrane of the perivisceral chamber does so; and that it is really the homologue of the third tunic there can be little doubt. We have seen that the blood flows between this lining membrane and the mantle, and between

[1] Plate LXVI. figs. 1, 2, 3.

[2] Report Brit. Assoc. 1852, Transactions of the Sections, p. 76.

an involution of it and the viscera, exactly as it would do if, in the Ascidian, the atrial membrane were a little more extensively developed; only in the former case the membrane closely invests the viscera, and is in contact with the mantle, leaving defined blood-channels or lacunes. In both cases the space circumscribed by this membrane opens externally, and in both cases, too, it receives the products of the genitalia on their passage outwards. Much more might be urged in confirmation of this view; but it is not intended, on the present occasion, to enter upon the details of this branch of the subject. Indeed my knowledge of the anatomy of the *Ascidiæ* is too limited to permit me to do so satisfactorily. I can therefore only hope that Mr. HUXLEY will shortly publish his researches bearing upon this matter, for assuredly no one is better prepared than he is to discuss it, as no one has a more extended knowledge of the morphology of the *Mollusca*, and a more complete and accurate acquaintance with the anatomy of the *Ascidiæ*.

Taking it for granted, then, that the atrium and the perivisceral chamber are homologous, the question arises, what light does this fact throw upon the function of the latter? In the *Ascidiæ*, the atrium communicating freely with the surrounding element might be considered as a sort of rudimentary water-system, by those who believe in the existence of such a system. Its function, however, seems to be that of excretion. That portion of it denominated the cloaca is for the outlet of the branchial currents, and at the same time for the discharge of the fæces, and of the ova or spermatozoa, according to the sex of the individual. But the other portion must have some special office to perform; and as its walls are washed by the blood, it would seem probable that it is for carrying out of the system the deleterious or effete nitrogenous matters. At the same time it seems not unlikely that this extension of the atrium may be to facilitate the discharge of the redundant fluid, which having entered the blood, is supposed to pervade the tissues of these animals. Thus the atrium may be viewed as performing the two great functions of a renal apparatus.

This atrial membrane is found in the most rudimentary condition in the *Polyzoa*, for instance, in *Fredericella sultana*. In this species the membrane lining the polyzoon, or that corresponding to the mantle or outer tunic, is invaginated at the orifice of the cell and encloses the upper portion of the animal with a third tunic. When the polype is exserted, this is only partially everted. It must be through the agency of this membrane that the effete, nitrogenized matter is eliminated, as well as the superfluous water, if any such discharge takes place.

The Ascidians, as has been shown, exhibit the next step of development in the arrangement of this membrane into the form of an atrium, into which the water is admitted. Then come the Brachiopods, in which the atrium is largely developed, and considerably modified; but now the external communication is much restricted. The most interesting change, however, is in the structure of the excretory channels or oviducts, which have assumed a glandular character. Thus one portion of the atrial membrane has become specialized, and probably performs one of the functions of a kid-

ney; whilst the other, that is, the lining membrane of the perivisceral chamber, and its various ramifications, must execute the complementary renal office. It has been pointed out that this chamber is everywhere in connexion with the various systems of blood-lacunes; the ramifications in the mantle follow these systems even to the circumpallial vessel, which also lies in the midst of blood-channels. It therefore seems impossible not to conclude that this peculiar arrangement and excessive development of the atrium is to facilitate the evacuation of some matter from the blood, probably little more than pure water.

Some fluid undoubtedly fills the perivisceral chamber, and as it communicates externally, it might be supposed that water would be received in this way. It has been stated, however, that the passages are so constructed that they would not readily admit fluid, though it might easily be discharged by them, the arrangement being very similar to that which obtains at the points of entrance of the ureters into the bladder of the higher animals. And, moreover, the ramifications of this chamber into the pallial lobes are inexplicable, unless it be assumed that they are connected with the discharge of some matter from the blood-system. It must be admitted, nevertheless, that the perivisceral chamber with its ramifications is apparently the equivalent of that which in the other Mollusks is usually denominated the water-system, and into which the external water is supposed to be admitted.

The atrial membrane will probably be found in all the *Mollusca* in various states of development, in some performing the two functions above distinguished by separate portions, in others having these portions, and therefore their functions, more or less united or blended together, as is probably the case in *Doris*, in which the great sinus, designated the kidney[1], stretching along the liver, and following the ramifications of the arteries, is throughout more or less glandular. This renal sinus is also remarkable for the richness of the vascular network in its membranous walls, reminding us forcibly of the peculiar condition of the parietes of the perivisceral chamber.

Again, in the Cephalopods, the renal follicles appended to the venous trunks in the so-called pericardium appear to perform the office of a kidney, while the extension of this cavity is probably the equivalent of the perivisceral chamber and its prolongations, having perhaps to discharge fluid eliminated from the blood instead of receiving it from the exterior. Without wishing to press unduly this suggestion, for it is little more, it may be asked, whence the necessity for supposing that water is admitted direct into the so-called water-system?

Be this, however, as it may, it may perhaps be concluded that the atrial wall of the Ascidian, and the lining membrane of the perivisceral chamber in the Brachiopod, are the homologues of the kidney and membrane composing what is usually designated the water-system in the *Mollusca* generally.

[1] Hancock and Embleton, "On the Anatomy of Doris," Philosophical Transactions, 1852, pp. 227, 228.

Nervous System.

This, like all the other organs, has been hitherto imperfectly described, though its examination does not present any peculiar difficulties; on the contrary, the nerves are very distinctly displayed, and can be easily traced. The nervous element, however, on the whole, exhibits a rather low state of development, lower, undoubtedly, than that of the Lamellibranchs, and not very much higher than that of the Ascidians. As in all true Mollusks, the ganglionic centres are placed in connexion with a nervous collar surrounding the œsophagus.

In *W. australis* the collar[1] is situated at the commencement of the alimentary tube, and there are five nervous centres, three of which, on account of their superior size, may be assumed to be the principal œsophageal ganglia. These lie amidst blood-lacunes, between the two membranes forming the anterior wall of the perivisceral cavity immediately below the œsophagus, or rather, on account of the mouth being bent down, behind it. One, the largest, is central and anterior; the other two form a pair, and are lateral and posterior. The former is flattened or depressed, and elongated transversely across the median line; the anterior and posterior margins are parallel, the sides slope inwards and backwards; at each side in front it is prolonged into a stout nerve, which immediately divides into an upper and a lower trunk. The latter is considerably the smaller, and goes to supply the brachial apparatus, running along the brachial ridge below the cirri.

The other trunk does not send any of its branches to the ventral pallial lobe, as it has been stated to do; but it supplies all the nerves of the dorsal lobe, besides others to the anterior wall of the perivisceral chamber and to the occlusor muscles. A single nerve or two only are sent to the wall of the chamber, and these pass from the root of the trunk; the trunk then advances upwards within the parietes, and on reaching the external margin of the muscles the filaments separate and form a loop[2], from which numerous twigs, dividing and subdividing, enter both sides of the extremity of the posterior occlusor, richly supplying it. This rather peculiar and beautiful arrangement of nerves has hitherto escaped observation, although the loop has been described and figured[3]. The trunk-nerve is continued from the end of the loop round the outer margin of the anterior occlusor muscle, giving to it a few twigs similar to those supplied to the posterior occlusor. It then gives off seven pallial nerves; other two pallial nerves pass off from the loop; thus there are nine sent to each side of the dorsal lobe, all of which run in a radiating manner in connexion with the outer layer of the inner lamina, dividing dichotomously three or four times, though not very regularly. I have entirely failed to detect the circumpallial nerve described by Professor Owen[4], and cannot but suppose that the delicate muscular cord[5], previously mentioned as running within the margin at

[1] Plates LII. fig. 10; LVI. fig. 1; LVII. fig. 2; LXII. fig. 11; LXIII. fig. 2.
[2] Plate LXII. figs. 14, 15.
[3] Introduction to Davidson's 'British Fossil Brachiopoda,' p. 12. pl. 2. fig. 2.
[4] Ibid.
[5] Plate LVIII. fig. 6.

the roots of the setæ, has misled this distinguished anatomist. The terminal twigs have been followed, with the aid of the microscope, until from extreme tenuity they could no longer be seen. Had such a nerve existed it could hardly have escaped detection.

The two lateral or posterior ganglia are fusiform, being elongated in the antero-posterior direction; they are placed one at each side of the median line, a little apart from each other, and are attached by one extremity to the posterior margin of the central ganglia. These extremities have the appearance of being united across the middle line by a cord or commissure, which is more distinct than usual in *W. cranium*. The other extremities are prolonged, and assuming the character of nerves, converge backwards, and at the point where the wall of the perivisceral chamber is attached to the occlusor muscles, they each divide into two trunks,—the ventral pallial, and the posterior or peduncular nerves. The latter, running backwards, one on each side of the middle line, pass from the parietes, and penetrating these muscles, run downwards in the midst of their fibres; on reaching their extremities they turn outwards, and running under the base of the ventral adjustor muscle, stretch backwards in connexion with the wall of the body[1]; they then pass one on each side of the peduncular muscle and divide into two branches, one of which becoming applied to the peduncular capsule, supplies it with two or three twigs, which can be traced to the border of the foramen. This branch also gives off a twig, which is lost in the substance of the peduncle. The other branch runs backwards in connexion with the parietes, and dividing two or three times, sends its twigs to the margin of the foramen.

The pallial nerves, which are larger than the peduncular, pass outwards, running in the walls of the body; they each divide immediately into two portions, both of which turning forward reach the ventral lobe; they then divide again four or five times dichotomously, and distribute numerous twigs to the margin, supplying it as richly as the dorsal nerve does the dorsal lobe. The main branches of the pallial nerves of both lobes run for some distance between the trunks of the great pallial sinuses, which they ultimately cross diagonally; but afterwards the branches of the nerves do not in the least conform to the ramifications of the sinuses. Four or five other nerves pass from the outer side of the lateral ganglia to supply the anterior wall of the body. Each of these takes its origin by two or three delicate roots.

The lateral ganglia, with the two peduncular nerves, appear to have escaped notice up to this time, unless two delicate filaments mentioned by Professor Owen[2] "as coming off from the lower part of the œsophageal circle near to the origin of the pallio-branchial trunk" may be supposed to represent them, though they are more probably the nerves which supply the anterior wall of the body.

The central ganglion forms the under side of the collar, and the cord which completes it is apparently a simple delicate nervous filament, the extremities of which are united to the ganglion, one at each side, near to the point where the brachial and dorsal pallial nerves separate. At each side close to the ganglion the cord swells a little and forms a

[1] Plate LII. figs. 2, 3. [2] Ibid.

minute round ganglion, from which issues a delicate filament; but these cannot be traced far on account of the large blood-lacunes situated at the root of the gullet; and indeed neither these ganglia nor the filaments, which are all that has been observed of the visceral nervous system, have been determined with sufficient accuracy. On the upper or anterior portion of the collar there are two inconspicuous ganglia, which are small, though considerably larger than those just alluded to; they are elongated transversely, and are placed considerably apart, one on each side of the median line; they give off a few minute filaments, which go to the parts immediately about the mouth, but their exact destination could not be determined, as the tissues are very opake and the filaments excessively minute. These ganglia are apparently the homologues of the labial ganglia of the Lamellibranchs, and probably of that portion of the cerebroids in the encephalous *Mollusca* which gives nerves to the lips and channel of the mouth. The cord with these two pairs of minute ganglia, as well as the large subœsophageal ganglia, lie between the two membranes composing the parietes of the body; so it would appear that these important organs are bathed in the blood flowing in the peripheral lacunes.

No material variation has been observed in the ganglia or nerves in any of the articulated Brachiopods. In *W. cranium*[1], however, the subœsophageal ganglia are slightly altered in form. The central one is narrower than in the other species, and the lateral pair are thickest in front and taper backwards.

In all, the nerves are distinctly striated, as if composed of nerve-tubes, and each is apparently provided with a neurilemma. By far the greater portion of the ganglionic mass, as already pointed out, is placed below the alimentary tube. This is not, however, by any means exceptional in the *Mollusca*; and the ganglia do not exhibit that distinct globular structure so common in these animals, but seem to be composed of minute granules. The structure, however, of the central portions of the system is difficult to observe, on account of the thickening of the membranes with which they are in connexion.

No organs of special sense have been observed, and if any such exist they will probably be in a very rudimentary condition. Indeed, sight, hearing or smell could be of little use to animals like the Brachiopods, deprived of locomotion, and firmly fixed for the whole period of their lives to one spot. Messrs. FORBES and HANLEY, in their 'British Mollusca,' regard as ocelli and otilitic capsules the red spots at the bases of the setigerous follicles in the mantle of *T. caput-serpentis*; but these are probably nothing more than glandular matter in connexion with the growth of the setæ. I have not, however, examined this animal alive, an advantage that these naturalists have apparently enjoyed.

I have not succeeded in detecting the œsophageal ganglia in *Lingula*. Professor OWEN[2] speaks of the subœsophageal ganglia, and they are also mentioned by Dr. C. VOGT[3]; but from what is stated in the memoir, it is pretty evident that the latter physiologist did not satisfactorily demonstrate their existence. The pallial lobes are copiously sup-

[1] Plate LXII. figs. 12, 13. [2] Ibid. [3] *Op. cit.*

plied with nervous filaments, which stream in a radiating manner towards the margin; those more particularly mentioned by Professor OWEN as supplying the muscles, have been described as blood-channels for reasons previously given.

Having now gone over the whole anatomy of these animals, it is necessary to make a few concluding remarks as to their affinities. But before entering upon these, a word or two may be said respecting the growth of the shell; to add anything on its structure would be mere supererogation, Dr. CARPENTER[1] having fully and accurately treated on this interesting portion of the subject. In respect to the increment, this takes place, as in all mollusks, mainly at the margin of the shell, and here the mantle in the *Terebratulidæ* presents a peculiar appearance. When the shell is dissolved in acid, the free border, which projects beyond the marginal fold, and which is applied to the extreme edge of the shell, can be examined with advantage. The pallial cæca are then completely exposed appended to the membrane in various stages of development, and the spaces between them are found studded all over with rather large, clear, oval, cell-like spots[2], which are arranged with considerable regularity in rows, so that those in the approximate rows alternate. These spots apparently correspond to the bases of the prismatic columns of the shell; and if it be allowed that they represent spaces in which calcareous granules had been accumulated, it is easy to understand how the fibrous or columnar structure is formed. A succession of layers of such accumulated granules, deposited one after the other, would result in the peculiar shell formation of the *Brachiopoda*.

It has been stated by Dr. CARPENTER[3], and the statement is perfectly correct, that the extremities of the prisms are not visible on the external surface. He supposes that this arises from the incorporation of the periostracum with the terminations of the prisms. But there appears to be a thin, homogeneous, external layer or stratum of calcareous matter observable at the margin of the valves in young individuals, particularly of *T. caput-serpentis*, in which this layer is apparently thicker than usual. If this be correct, and I can scarcely doubt it, the shell of some species, at least, is composed of two layers, in which the structure is different; and thus in the Brachiopods the outer and inner layers of the Lamellibranchs would seem to be represented.

It may likewise be remarked that this investigation appears to establish that there are two great types of form in the *Brachiopoda*, namely, the articulated and the unarticulated; which are characterized, not merely by the presence of a hinge in the one, and the deficiency of it in the other, but by several other important points in their structure. In the articulated division, the valves are opened by the muscles acting through the agency of a lever; in the unarticulated, by the pressure of fluid contained in the perivisceral cavity; hence the difference in the muscular arrangement previously described. In the former, too, the intestine terminates in a blind sac, while in the latter there is an ample anal aperture. These and many other points might be cited,

[1] Introduction to DAVIDSON's 'British Fossil Brachiopoda,' p. 23.
[2] Plate LVIII. fig. 8.
[3] *Op. cit.* p. 26.

showing the propriety of dividing these animals into two great groups, as was proposed in 1836 by M. DESHAYES[1]. Some objections might, perhaps, be raised to this, on account of *Productus* and *Aulosteges*, as neither have teeth or sockets, though both undoubtedly belong to the articulated group. But notwithstanding these deficiencies, the valves are related to each other as if hinged, and the cardinal process is so locked into the beak of the opposite valve, as to have prevented any lateral movement. The distinctive feature, however, is not in the mere fact of articulation, but in the mode of opening the valves; and in these two genera there was apparently no deviation in this respect from the rest of the group.

With regard to the affinities of the Brachiopods, it is impossible not to be struck with the strong resemblance that exists between the organization of these animals and that of the *Tunicata* and *Polyzoa*. In the first place, they are all three, with a few exceptions, attached to foreign bodies; and in all, the respiratory organ is appended to the mouth, serving at the same time the purpose of sustentation. The intestine has a neural flexure in the *Brachiopoda* and *Polyzoa*, and the arms of the former are constructed upon the same plan as those of a Hippocrepian Polyzoon, as is at once obvious on the examination of the lophophore of *Plumatella*, for instance. It is interesting to mark the gradual change of these organs from their simplest form to their full and complete development in the *Brachiopoda*. In the lower forms of the *Polyzoa* the cirri or tentacles are arranged in a simple circle around the mouth, but in *Fredericella* the base upon which they are supported is angulated a little at each side. In *Plumatella* the angles are produced so as to give to the base a horseshoe form; in fact, to provide two rudimentary arms, along both sides of which the cirri are arranged in a single series. In the next step in the development of these organs the cirri of the two sides are approximated, forming a close-set double series; the arms are much elongated and spirally coiled, and they are thus at once transformed into the brachial apparatus of the Brachiopod: the arms of *Lingula* and *Rhynchonella* are complete, only they are turned forward instead of backward.

The relation of the two forms is also manifested by the muscular system. The polype retractors and the opercular muscles of *Paludicella* seem to be homologous with the adjustor muscles, their position being very similar; and it is also interesting to find that their function is not altogether different, for in addition to the retraction of the polype, they have the power of depressing and moving from side to side the lophophore, much in the same way as the adjustors move the shell in the *Terebratulidæ* upon the peduncle. It has likewise been pointed out by Professor HUXLEY[2], that the occlusor and divaricator muscles of these latter animals act in exactly the same manner as the muscles similarly named, which open and close the beaks or valves of the avicularium or bird's-head process of the Cheilostomatous *Polyzoa*. Thus in these curious organs we see the same peculiar disposition of muscles which characterizes the articulated division; and

[1] LAMARCK, Animaux sans Vertèbres, 2me ed. tom. vii. p. 309.

[2] English Cyclopædia, Nat. Hist. vol. iii. column 859, 1855.

in *Paludicella* there is a set of muscles[1] which acts in the same way as the parietals, or those so instrumental in opening the valves of the unarticulated Brachiopods, as exhibited in *Lingula*. The set alluded to have been likewise denominated parietal muscles, and they are in connexion with the mantle or lining membrane of the cell, their extremities being attached to the cell-wall. By their contraction they diminish the space within which the polype lies, and thus the contained fluid forces it upwards, and at the same time unrolls the tubular orifice; just as the fluid in the perivisceral chamber is made to open the valves by the contraction of the anterior and posterior parietes. From their position and function there can be little doubt that these muscles in *Lingula* and *Paludicella* are homologous. It is also worthy of remark, that the punctures in the cell walls of *Lepralia* resemble the perforations in the shell of the *Brachiopoda*, as has been pointed out by Dr. CARPENTER[2].

The Brachiopods are also very closely connected with the *Ascidiæ*, though the former are more highly organized, as evinced by the greater completeness of the nervous system. In both, the principal ganglionic masses are below the alimentary canal. The relations are however best displayed by the circulatory system, which is developed on the same plan in both forms; the only difference being that the large blood-lacunes of the Ascidian are reduced in size, and are formed for the most part into minute, narrow channels by the development of the atrial membrane, and by its collapse upon the viscera, and its extension and reflexion upon the walls of the body. In these respects, however, the genus *Phallusia* will bear comparison with the Brachiopods. In both, too, there is the same unilocular heart, imperfect arterial system, and almost complete deficiency of veins. The breathing organ in the Ascidian has undergone a considerable change; but whether it is or is not morphologically the same as the arms of the *Brachiopoda*, these organs in both forms are similarly related to the mouth.

The affinity of the Brachiopod to the Ascidian is also seen in the intimate connexion that exists between the mantle and the shell; and the cæcal processes of the former, which penetrate the shell, are probably the homologues of the vascular prolongations which nourish the test of the latter.

The inferiority of the Brachiopods to the Lamellibranchs is evinced alike by the digestive, the circulatory and respiratory organs, and by the nervous system, notwithstanding that the muscular apparatus might be assumed to be developed upon a higher type.

Notes added February 1859.

No. 1.—I have been under the necessity of naming this species, for it does not agree, as far as can be ascertained, with any described form. It was received along with two or three specimens of *L. anatina*, and it was only after the shell had been removed, and the

[1] HANCOCK, "On the Anatomy of the Freshwater Bryozoa," &c., Ann. and Mag. Nat. Hist. vol. v. p. 173 (1850).

[2] Proceedings of the Royal Society, vol. vii. p. 36 (1854).

mantle carefully examined, that its distinctive character was observed. It is, however, smaller, considerably narrower in proportion to its length, and has the shell of a brighter green colour than the species with which it was associated; but the most important character is found in connexion with the pallial lobes, in which the pallial sinuses do not assume the form of gill-like plicæ arranged in parallel order; on the contrary, they are much branched (Plate LXVI. figs. 1 and 2), resembling the pseudo-vascular ramifications of some of the articulated Brachiopods.

The specimen examined was 2 inches long and $\frac{7}{8}$ths of an inch broad.

No. 2.—The valves of the Brachiopods are undoubtedly related anatomically, as stated in the text, though perhaps they ought both to be considered dorsal as well as those of the Lamellibranchs, as has been pointed out by Professor HUXLEY. If this view be correct, the only difference in the arrangement of the valves of the two classes will be that, while in the latter they are united *along* the dorsal ridge, they are articulated *across* the back in the Brachiopods.

No. 3.—Dr. VOGT, in his well-known paper 'On the Anatomy of *Lingula anatina*,' previously quoted in the text, has given a minute, though erroneous description of the so-called gill-organ, having apparently entirely misunderstood the anatomy of the part. He has certainly failed to recognize the true nature of the great pallial sinuses, is not aware that they communicate with the perivisceral chamber, and what he describes as the vascular ramifications of the "gill-leaf" are not vessels at all; the "gill-leaf" itself is a portion of the inner pallial lamina, and the "cilia-leaf" is the remainder of the mantle, being chiefly composed of the outer lamina.

In both the species of *Lingula* that I have examined there is a white line running along the outer wall of the pallial sinuses (Plates LXIV. figs. 1 and 2 *d*; LXVI. fig. 1 *c*, *e*), which, upon a cursory inspection, might be erroneously supposed to be of the nature of a similar line which is observed in the articulated Brachiopods, and which in them is produced by the base of the membrane suspending the genitalia. In *Lingula*, however, this line is, as just stated, in connexion with the *outer* pallial lamina, while in the articulated Brachiopods it is connected with the *inner* lamina. And moreover these lines in the central and lateral sinuses of the latter are united to that of the trunk-sinus, but they are not so united in *Lingula*; those of the lateral branches in it reach no further than the margins of the trunk-sinus, a considerable space being left between their terminations and the line in that sinus. This fact is conclusive against these lines being vascular ramifications, and yet it would seem that they are the vessels of the "gill-leaf," according to Dr. VOGT, for there is nothing else to be found in connexion with the mantle that at all answers to his description, which is sufficiently accurate on this point. These vascular ramifications are, says this eminent anatomist, "surrounded by a translucent space, which is produced by a hollow canal in which the vessels lie." This is exactly the appearance the white lines assume in relation to the pallial sinuses when

seen through the pallial membrane. Dr. VOGT likewise points out that the inner and outer branches of the so-called vessels do not appear to join the trunk-vessel, but supposes that this may be owing to their having been broken off on tearing up the specimen. His description, therefore, clearly answers to that of these white lines; he appears, however, to have examined them only from the surface. When the sinuses are laid open, the white lines are found to be produced by a solid, granular substance adhering to, and standing up in relief from, the outer walls. This substance is formed apparently by a thickening of the epithelial lining of the sinus, and has probably some function to serve in connexion with the perivisceral ramifications, but certainly is in no way connected with the blood-circulation.

The bladder-shaped enlargements (Plate LXIV. fig. 3 *e*, *e*) of the lateral pallial sinuses, alluded to by Dr. VOGT, are nothing more than swellings occasioned by the contraction of the pallial or marginal fold, which, pressing upon the extremities of the sinuses, throws their walls into wrinkles, and hence this peculiar appearance. But I have seen nothing like the ramifications of the so-called vessels described by him on the inner surface of these bladder-shaped enlargements, and am inclined to conclude that he has been misled by some fragments of the external epithelium which had been left adhering to their walls.

EXPLANATION OF THE PLATES.

PLATE LII.

Fig. 1. Dorsal view of *Waldheimia australis*, the shell having been removed:—*a*, pallial lobe; *b*, body; *c*, peduncle; *d*, great inner pallial sinuses giving branches to the margin; *e*, outer ditto, ditto; *f*, genitalia seen through the pallial membrane; *g*, red matter of ditto; *h*, marginal fold; *i*, setæ; *j*, circumpallial vessel; *k*, extreme pallial margin; *l*, median fissure, corresponding to longitudinal plate in valve; *m*, depression occasioned by the hinge-plate and the bases of the crura; *n*, orifices for the passage of the crura; *o*, ridge formed by the union of the pallial margins; *p*, extremities of anterior occlusors; *q*, ditto of posterior occlusors; *r*, ditto of divaricators; *s*, ditto of dorsal adjustors; *t*, liver seen through the wall of the body.

Fig. 2. Ventral view of the same; the letters up to and including *k* correspond to those of fig. 1:—*l*, extremities of occlusor muscles; *m*, ditto of divaricators; *n*, ditto of accessory divaricators; *o*, ditto of ventral adjustors; *p*, ditto of peduncular muscles; *q*, cæcal extremity of intestine, seen through the wall of the perivisceral chamber; *r*, peduncular nerves.

Fig. 3. Ventral view of variety of *W. australis*: the letters correspond to those of fig. 2. The divaricators and their accessories are united.

Fig. 4. Internal view of dorsal valve of *W. australis*, showing the calcareous loop:—

a, hinge-plate; *b*, dental sockets; *c*, hinge-process; *d*, longitudinal plate or septum; *e*, crura; *f*, crural processess; *g*, upper or dorsal member of loop; *h*, lower ditto; *i*, transverse portion of ditto.

Fig. 5. Portion of dorsal valve of *W. cranium*:—*a*, dental sockets; *b*, hinge-process; *c*, crura of loop; *d*, crural processes; *e*, portion of upper or dorsal member of loop; *f*, impression of dorsal adjustors.

Fig. 6. Lateral half of ventral pallial lobe of *Terebratulina caput-serpentis*, exhibiting arrangement of spicula:—*a*, marginal fold; *b*, setæ; *c*, spicula overlying great pallial sinus; *d*, *d*, ditto overlying the branches of the sinus.

Figs. 7, 8. Two spicula highly magnified.

Fig. 9. Lateral half of ventral pallial lobe of *Megerlia truncata*, exhibiting arrangement of spicula:—*a*, marginal fold; *b*, genitalia; *c*, *c*, spicula.

Fig. 10. General view of the viscera of *W. australis*, the perivisceral chamber having been laid open from above:—*a*, portion of dorsal pallial lobe; *b*, ditto of ventral lobe; *c*, peduncle; *c'*, capsule of ditto; *d*, extremities of anterior occlusor muscles, that on the right partially removed; *d'*, ditto of posterior occlusors, the right one also partially removed; *d''*, ventral extremities of occlusors; *e*, divaricators; *e'*, extremities of the same attached to cardinal process; *e''*, accessory divaricators; *f*, *f*, dorsal adjustors, cut through; *g*, ventral adjustors; *h*, œsophagus; *i*, stomach; *j*, intestine; *k*, ducts of the right hepatic lobes, the latter having been removed; *k'*, anterior hepatic lobe of the left side, seen through the wall of the perivisceral chamber; *k''*, posterior ditto; *l*, lateral gastro-parietal band; *m*, central ditto; *n*, ilio-parietal ditto; *o*, dorsal mesentery; *p*, ventral ditto; *q*, laminated portions of oviducts (auricles of the pseudo-hearts); *r*, orifice leading into ditto; *s*, *s*, *s*, *s*, genital organs, those on the right partially removed; *t*, heart, dilated; *t'*, *t'*, *t'*, accessory pulsatile vesicles; *u*, branchio-systemic vein bringing the blood from the arms or gills and the rest of the body to the heart; *v*, *v*, *v*, ventral pallial or genital arteries; *v'*, *v'*, dorsal ditto; *x*, œsophageal ganglia, giving off nerves.

PLATE LIII.

Fig. 1. Dorsal view of *Terebratulina caput-serpentis*, deprived of the shell:—*a*, pallial lobe; *b*, body; *c*, peduncle; *d*, *d*, great pallial or genital sinuses; *e*, *e*, ramifications of ditto; *f*, muscular ties passing between the walls of ditto; *g*, genitalia seen through the walls of ditto; *h*, marginal fold; *i*, setæ; *j*, extreme pallial margin; *k*, depressions corresponding to the bases of the crura; *l*, ridge formed by the union of the pallial margins; *m*, edge of dorsal mesentery; *n*, *n*, liver seen through the walls of the perivisceral chamber; *o*, extremities of anterior occlusors; *p*, ditto of posterior occlusors; *q*, ditto of divaricators; *r*, ditto of dorsal adjustors.

Fig. 2. Ventral view of the same; the letters up to *j* agree with those of fig. 1:—*k*, extremities of occlusor muscles; *l*, ditto of divaricators; *m*, ditto of ventral adjustors; *n*, ditto of peduncular muscle; *o*, *o*, peduncular nerves.

Fig. 3. Dorsal view of the animal of *W. cranium*:—*a*, pallial lobe; *b*, body; *c*, peduncle; *d*, *d*, great inner pallial sinus; *e*, outer ditto; *f*, genitalia, appearing through the walls of the sinuses; *g*, marginal fold; *h*, setæ; *i*, circumpallial vessel; *j*, extreme pallial margin; *k*, two lobes corresponding to cavities at the sides of the foramen; *l*, similar lobes corresponding to cavities in the umbonal region of dorsal valve; *m*, ridge resulting from the union of the pallial margins; *n*, extremities of anterior occlusors; *o*, ditto of posterior occlusors; *p*, ditto of dorsal adjustors; *q*, ditto of divaricators.

Fig. 4. Ventral view of the same; the letters up to *k* as in fig. 3:—*l*, extremities of occlusor muscles; *m*, ditto of divaricators; *m'*, portions of ditto corresponding to the accessory divaricators; *n*, ditto of ventral adjustors; *o*, ditto of peduncular muscle; *p*, *p*, peduncular nerves.

Fig. 5. General view of perivisceral chamber of *T. caput-serpentis* seen from above:—*a*, portion of dorsal pallial lobe; *b*, peduncle; *c*, capsule of ditto; *d*, ridge formed by the union of the pallial margins; *e*, stomach; *f*, intestine; *g*, *g*, lateral lobes of the liver; *h*, laminated portions of oviducts; *i*, orifices leading into ditto; *j*, anterior occlusor muscles; *k*, posterior ditto; *l*, *l*, *l*, dorsal adjustors cut through; *m*, ventral ditto; *n*, divaricators; *n'*, extremities of ditto attached to cardinal process; *o*, dorsal mesentery; *p*, ventral ditto; *q*, lateral gastro-parietal bands; *r*, ilio-parietal bands; *s*, heart, dilated; *t*, accessory pulsatile vesicle; *u*, branchio-systemic vein; *v*, ventral pallial artery; *w*, dorsal ditto; *x*, peduncular artery.

Fig. 6. Enlarged view of a portion of the mantle of *Megerlia truncata*, exhibiting the spicula undisturbed:—*a*, *a*, spicula.

Fig. 7. One of the spicula more highly magnified.

Fig. 8. Much enlarged view of a portion of the genitalia of *W. australis*:—*a*, pallial membrane; *b*, *b*, yellow ovigerous substance; *c*, *c*, red matter supposed to be the male secreting organ.

Fig. 9. Oviduct of *W. cranium* as seen through the wall of the perivisceral chamber:—*a*, portion of genital organ; *b*, genital or pallial artery; *c*, internal laminated portion of oviduct; *d*, tubular portion of ditto; *e*, external orifice.

Fig. 10. Oviduct of *W. australis*:—*a*, portion of anterior wall of perivisceral chamber; *b*, ditto of ilio-parietal band; *c*, laminated portion of oviduct (auricle of pseudo-heart); *d*, orifice leading into ditto from perivisceral chamber; *e*, tubular portion of organ; *f*, external orifice seen through the wall of the chamber; *g*, ventral pallial artery; *h*, accessory pulsatile vesicle in contracted state.

PLATE LIV.

Fig. 1. General view of the viscera of variety of *W. australis*, seen from above:—*a*, portion of dorsal pallial lobe; *b*, *b*, great inner pallial sinuses, that on the left laid open; *b'*, outer ditto; *c*, genitalia; *d*, peduncle; *e*, capsule of ditto; *f*, *f*, anterior occlusors; *f'*, *f''*, posterior ditto, the left one partially removed to exhibit gastro-parietal band; *g*, divaricators; *h*, *h*, dorsal adjustors cut through; *i*, ventral adjustors; *j*, ventral extremities of occlusors; *k*, stomach; *l*, intestine; *m*, right lobes of the liver, seen through the wall of the perivisceral chamber; *m'*, portion of anterior hepatic lobe of left side; *n*, *n*, hepatic ducts of anterior and posterior lobes of the same side; *o*, dorsal mesentery; *p*, one of the lateral gastro-parietal bands; *q*, central gastro-parietal band; *r*, heart, dilated; *s*, ventral accessory pulsatile vesicles; *s'*, one of the dorsal ditto, contracted; *t*, branchio-systemic vein; *u*, dorsal pallial artery; *v*, ventral ditto; *w*, peduncular artery; *x*, posterior extremities of ventral genitalia; *y*, laminated portion of oviducts; *z*, orifice leading into ditto.

Fig. 2. General view of the viscera of *W. cranium*, seen from above; the letters agree with those of fig. 1 up to and including *l*:—*m*, hepatic lobes; *n*, dorsal mesentery; *o*, lateral gastro-parietal bands; *p*, ilio-parietal ditto; *q*, heart in contracted state; *r*, branchio-systemic vein; *s*, *s*, dorsal pallial artery; *t*, ventral ditto; *u*, peduncular artery, running along margin of ventral mesentery; *v*, posterior extremity of right dorsal genital organ; *w*, posterior extremities of ventral genitalia; *x*, laminated portion of oviducts.

Fig. 3. Intestine of the same, enlarged:—*a*, upper extremity; *b*, posterior cæcal extremity; *c*, *c*, portions of oviducts; *d*, ventral mesentery; *e*, *e*, thickened ridges of ditto; *f*, peduncular artery.

Fig. 4. Cæcal or lower extremity of the same intestine seen in the compressor:—*a*, walls of intestine; *b*, cavity of ditto; *c*, ventral mesentery; *d*, *d*, thickened ridges of ditto.

Fig. 5. Transverse section of intestine a little below the stomach:—*a*, *a*, portions of ilio-parietal bands; *b*, portion of ventral mesentery; *c*, external sheath of intestine; *d*, muscular layer of ditto; *e*, *e*, folds of mucous membrane.

Fig. 6. Another section of the same intestine a little lower down.

Fig. 7. A third section a little above cæcal extremity; the letters of the two last correspond to those of fig. 5.

Fig. 8. Side view of lower portion of intestine of *W. australis*:—*a*, *a*, ventral mesentery; *b*, lacunes or blood-channels, between the layers of ditto; *c*, cæcal extremity of intestine; *d*, ridges in mesentery.

Fig. 9. Cæcal extremity of intestine seen through the dorsal wall of the perivisceral chamber:—*a*, portion of dorsal wall of chamber; *b*, bases of the pallial cæca; *c*, imperforate extremity of intestine.

Figs. 10, 11. Transverse sections of intestine: letters as in fig. 5.

PLATE LV.

Fig. 1. Animal of *W. australis* deprived of the shell, and the pallial lobes turned back so as to expose the brachial apparatus and anterior wall of the body:—*a*, portion of ventral lobe; *b*, dorsal ditto; *c*, *c*, genitalia appearing through the walls of the pallial sinuses; *d*, base of membrane suspending genitalia; *e*, *e*, umbonal region; *f*, peduncle; *g*, spiral portion of brachial apparatus; *h*, lateral portions of ditto; *i*, *i*, *i*, cirri; *j*, brachial fold, a few cirri having been removed to expose it and the anterior wall of the body; *k*, position of mouth, which is concealed under the fold; *l*, occlusor muscles seen through the anterior wall; *m*, left oviduct lying within the anterior wall; *n*, orifice leading into oviduct.

Fig. 2. View of brachial apparatus and anterior wall of the body of *Terebratulina caput-serpentis*:—*a*, portion of ventral pallial lobe; *b*, ditto of dorsal lobe; *c*, *c*, genitalia, seen through the walls of the pallial sinuses; *d*, base of suspending membrane of genitalia forming a reticulated line; *e*, muscular ties uniting the walls of pallial sinuses; *f*, umbonal region; *g*, peduncle; *h*, lateral portions of arms; *i*, spiral portions of ditto; *j*, cirri; *k*, *k*, roots of cirri that have been removed; *l*, *l*, brachial fold; *m*, groove formed by ditto; *n*, mouth; *o*, occlusor muscles appearing through the anterior wall; *p*, divaricators ditto; *q*, ventral adjustors ditto; *r*, liver ditto; *s*, right oviduct ditto; *t*, orifice leading into oviduct.

Fig. 3. View of brachial apparatus and anterior wall of the body of *Rhynchonella psittacea*:—*a*, ventral pallial lobe; *b*, dorsal ditto; *c*, *c*, genitalia imperfectly developed; *d*, base of suspending membrane of ditto appearing as a reticulated line; *e*, muscular ties passing between the walls of the genital sinuses; *f*, umbonal portion of animal; *g*, peduncle; *h*, the left arm partially uncoiled; *i*, base of the right arm, the arm itself having been removed; *j*, cirri; *k*, brachial fold; *l*, mouth; *m*, occlusor muscles, seen through the anterior wall; *n*, divaricators ditto; *o*, liver ditto; *p*, œsophagus ditto; *q*, edge of dorsal mesentery ditto; *r*, *r*, *r*, *r*, oviducts ditto; *s*, orifices leading into oviducts.

Fig. 4. Transverse section of root of œsophagus of *W. australis*, exhibiting the great œsophageal blood-lacunes:—*a*, *a*, base of arms; *b*, *b*, efferent brachial sinuses; *c*, two tubercles on the walls of ditto, function not known; *d*, *d*, efferent brachial canals; *e*, dorsal mesentery; *f*, ventral ditto; *g*, mucous membrane lining œsophagus; *h*, muscular wall of œsophagus; *i*, outer sheath of ditto; *j*, *j*, great œsophageal lacunes; *k*, large sinus within the layers of the mesenteric membrane; *l*, portion of the central œsophageal ganglion; *m*, *m*, roots of dorsal pallial nerves; *n*, œsophageal collar.

PLATE LVI.

Fig. 1. General view of the viscera of *W. australis*, the perivisceral chamber completely laid open:—*a*, portion of dorsal pallial lobe; *b*, peduncle; *c*, *c*, capsule of ditto; *d*, *d*, extremities of anterior and posterior occlusors, those of the right partially removed; *d'*, ventral extremities of occlusors; *e*, *e*, *e*, divaricators, that of the right side divided; *e'*, accessory divaricators; *f*, *f*, *f*, ventral adjustors, that on the right cut through; *g*, *g*, dorsal adjustors, cut through; *h*, peduncular muscle; *i*, œsophagus; *j*, stomach, with the biliary ducts exposed on the right, the hepatic lobes of that side having been removed; *k*, *k*, left hepatic lobes seen through the wall of the perivisceral chamber; *l*, intestine; *m*, dorsal mesentery; *n*, ventral ditto; *o*, ilio-parietal band; portions of the gastro-parietal bands are seen attached to the stomach; *p*, *p*, *p*, *p*, genitalia, those of the right side have their posterior extremities removed; *q*, oviduct; that on the right partially cut away so as to expose the tubular portion of the organ lying within the anterior wall of the chamber; *r*, heart, dilated; *s*, *s*, *s*, *s*, accessory pulsatile vesicles, also dilated; *t*, branchio-systemic vein; *u*, aorta giving off dorsal and ventral pallial arteries; *v*, peduncular artery; *w*, œsophageal ganglia; *x*, loop of pallial nerve giving branches to mantle, and occlusor muscles; *y*, pallial nerves; *z*, *z*, peduncular ditto.

Fig. 2. Transverse section of the base of the arms of *W. australis*:—*a*, portion of dorsal pallial lobe; *b*, ditto of ventral lobe; *c*, root of œsophagus seen through the anterior wall of the perivisceral chamber; *d*, liver ditto; *e*, anterior occlusor muscles ditto; *f*, *f*, bases of the lateral portions of the arms; *g*, *g*, ditto of spiral portions of ditto; *h*, membrane uniting the spirals; *i*, *i*, great brachial canals of ditto; *j*, *j*, small or efferent brachial canal; *k*, *k*, great brachial canal of lateral portions, that on the left laid open to show its connexion with the same canal of the spiral; *l*, *l*, *l*, *l*, small or efferent brachial canals of lateral portions; *m*, *m*, brachial pouches, opening into the perivisceral chamber; *n*, *n*, *n*, *n*, sheaths of calcareous loop; *o*, *o*, *o*, grooved ridge; *p*, *p*, *p*, brachial fold; *q*, *q*, cirri.

Fig. 3. Transverse section of spiral portion of arm much enlarged:—*a*, great brachial canal; *b*, small or efferent ditto; *c*, grooved ridge; *d*, bases of cirri; *e*, brachial fold; *f*, groove; *g*, membrane uniting spirals.

Fig. 4. Transverse section of genital organ:—*a*, *a*, lobules of ditto; *b*, genital or pallial artery; *c*, membrane suspending genitalia in pallial sinus; *d*, inner wall of sinus.

Fig. 5. Dorsal view of stomach, exhibiting the branchio-systemic vein laid open:—*a*, œsophagus; *b*, stomach; *c*, commencement of intestine; *d*, lateral gastro-parietal band; *e*, central ditto; *f*, heart; *g*, dorsal pallial artery; *h*, ventral ditto; *i*, branchio-systemic vein laid open; *j*, *j*, orifices leading into the gastric or visceral lacunes; *k*, hepatic ducts.

Fig. 6. Anterior or dorsal aspect of root of œsophagus, showing the connexion of the branchio-systemic vein with the great œsophageal lacunes:—*a*, outer sheath of œsophagus; *b*, muscular wall of ditto; *c*, mucous membrane of ditto; *d*, ventral mesentery; *e*, large sinus between the layers of ditto; *f*, *f*, dorsal pallial nerves; *g*, œsophageal collar; *h*, *h*, efferent brachial canals; *i*, *i*, efferent brachial sinuses; *j*, two tubercles on the walls of ditto, function unknown; *k*, *k*, great œsophageal lacunes; *l*, branchio-systemic vein laid open.

Fig. 7. Enlarged view of the heart attached to the stomach:—*a*, stomach; *b*, commencement of intestine; *c*, lateral gastro-parietal band; *d*, central ditto; *e*, dorsal mesentery; *f*, heart in contracted state; *g*, *g*, branchio-systemic vein opened to show its connexion with the heart; *h*, aorta; *i*, dorsal pallial artery; *j*, ventral ditto; *k*, portion of oviduct.

Fig. 8. Portion of lateral gastro-parietal band, exhibiting blood-channels or lacunes:—*a*, dorsal pallial artery; *b*, lacunes between the layers of membrane; *c*, *c*, the two layers composing the band.

PLATE LVII.

Fig. 1. Posterior view of the viscera of *W. australis*, the umbonal region having been removed:—*a*, dorsal surface of animal; *b*, ventral ditto; *c*, anterior occlusors; *c'*, posterior ditto; *c''*, ventral extremities of occlusors; *d*, divaricators; *d'*, accessory ditto; *e*, ventral adjustors; *f*, *f*, portions of dorsal ditto; *g*, stomach, the liver having been removed from the left side, the roots of the hepatic ducts are exposed; *h*, right hepatic lobes; *i*, intestine; *j*, *j*, lateral gastro-parietal bands; the central band is seen immediately above the heart; *k*, fissure corresponding to the longitudinal plate or septum of the dorsal valve; *l*, upper portion of ventral mesentery; *m*, *m*, genitalia; *n*, oviducts, attached to the intestine by the ilio-parietal bands; *o*, heart in contracted state, giving off two lateral arteries; *p*, *p*, accessory pulsatile vesicles; *q*, ventral pallial arteries; *r*, peduncular artery; *s*, orifices for the passage of the crura of the loop; *t*, brachial cirri; *u*, *u*, orifices leading into inner pallial sinuses; *v*, outer dorsal pallial sinus partially laid open; *w*, ventral ditto, ditto.

Fig. 2. Lateral view of the viscera of the same:—*a*, dorsal surface of animal; *b*, ventral ditto; *c*, *c*, anterior wall of perivisceral chamber; *d*, brachial spiral, the left lateral portion of the arm having been removed; *d'*, right lateral portion of ditto; *e*, great brachial canal; *f*, small or efferent ditto; *g*, brachial grooved ridge; *h*, sheath of transverse portion of calcareous loop; *i*, *i*, dorsal extremities of anterior and posterior occlusors; *j*, ventral portion of ditto; *k*, divaricators; *k'*, accessory ditto; *k''*, extremities of ditto attached to cardinal process; *l*, *l*, portions of ventral adjustors; *l'*, *l'*, portions of dorsal ditto; *m*, peduncle; *n*, peduncular capsule; *o*, peduncular muscle; *p*, œsophagus; *q*, stomach,

with the roots of the biliary ducts exposed, the left lobes of the liver having been removed; *r*, right lobes of the liver seen through the dorsal mesentery; *s*, intestine; *t*, portion of gastro-parietal band; *t'*, central ditto; *u*, ventral mesentery; *u'*, upper portion of ditto; *v*, right oviduct, the left one is almost entirely removed; *w*, heart; *x*, dorsal pallial artery; *y*, ventral ditto; *y'*, blood-sinus in mesenteric membrane; *z*, œsophageal ganglia.

Fig. 3. Longitudinal section of peduncle:—*a*, distal extremity; *b*, foreign matter adhering to ditto; *c*, horny sheath; *d*, muscular mass; *e*, *e*, walls of capsule; *f*, *f*, walls of perivisceral chamber; *g*, margin of orifice leading into capsule; *h*, peduncular muscle; *i*, right ventral adjustor; *j*, muscular enlargement attaching ditto to peduncle; *k*, right dorsal adjustor; *l*, muscular enlargement uniting the latter to peduncle.

Fig. 4. Ventral aspect of peduncle, the capsule laid open:—*a*, peduncle; *b*, muscular mass of ditto; *c*, horny sheath of ditto; *d*, walls of capsule; *e*, margin of orifice leading into ditto; *f*, *f*, irregular plications of the inner surface of ditto; *g*, extremity of peduncular muscle; *h*, ditto of accessory divaricators; *i*, portion of ventral wall of perivisceral chamber; *j*, ditto of dorsal wall of ditto.

Fig. 5. One of the setæ from the pallial margin of *W. australis*, much enlarged.

Fig. 6. A marginal seta of *T. caput-serpentis*:—*a*, follicle from which the seta originates; *b*, enlarged extremity of follicle, containing red glandular matter.

Fig. 7. Portion of the same seta more highly magnified.

Fig. 8. Two marginal setæ of *Lingula anatina*.

Fig. 9. Portion of the same, greatly enlarged, exhibiting transverse ridges.

PLATE LVIII.

Fig. 1. Transverse section of the brachial grooved ridge of *W. australis*:—*a*, base supporting cirri; *b*, brachial fold; *c*, groove; *d*, *d*, walls of great brachial canal; *e*, small or efferent ditto; *f*, *f*, *f*, epithelium; *g*, *g*, roots of cirri exhibiting their biserial arrangement; *h*, expanded bases of ditto, opening into the efferent brachial canal; *i*, *i*, plexus of blood-channels communicating with that in the wall of the great brachial canal; *j*, *j*, great brachial plexus; *k*, afferent brachial arteries leading from ditto into cirri; *l*, *l*, the same arteries passing up cirri.

Fig. 2. Transverse section of the same brachial grooved ridge, exhibiting its muscular system; the letters up to and including *h* correspond to those of fig. 1:—*i*, *i*, group of muscular fibres for elevating the cirri; *j*, *j*, ditto for contracting the groove and brachial fold; *k*, *k*, ditto, partially antagonistic to the last group, and for bringing forward or depressing the cirri; *l*, *l*, thin layer of muscular fibres, from which group *k* originates; *m*, epithelial lining of efferent brachial canal.

Fig. 3. Portion of brachial ridge, exhibiting the orifices leading into the cirri, the wall

of the efferent brachial canal laid open:—*a*, *a*, portions of the wall of this canal; *b*, orifices leading into the cirri; *c*, *c*, afferent brachial arteries; *d*, transverse channels of great brachial plexus; *e*, portion of the wall of great brachial canal; *f*, minute plexus at the base of brachial ridge.

Fig. 4. Terminal portions of two cirri deprived of their epithelium:—*a*, longitudinal ridge supporting afferent brachial artery; *b*, external lamina or keel; *c*, *c*, blood-corpuscles.

Fig. 5. Diagram of longitudinal section of marginal portion of valve in connexion with the mantle:—*a*, margin of valve; *b*, shell exhibiting prismatic structure; *c*, *c*, pallial cæca penetrating ditto; *d*, great pallial sinus; *e*, marginal vessel; *f*, outer lamina of mantle; *g*, external reticulated layer of ditto, in which the pallial cæca take their origin; *h*, homogeneous layer of outer lamina; *i*, inner lamina of mantle; *j*, epithelium; *k*, *k*, membrane lining pallial sinus; *l*, epithelium of ditto; *m*, outer pallial lacunes; *n*, inner ditto; *o*, marginal fold; *p*, one of the setæ; *q*, follicle of ditto; *r*, prolongation of glandular matter of follicle; *s*, marginal muscles; *t*, extreme pallial margin.

Fig. 6. Portion of pallial margin, the inner lamina partially removed:—*a*, extreme margin; *b*, marginal fold; *c*, *c*, setæ; *d*, follicles of ditto; *e*, prolongations of the glandular matter of the follicles; *f*, circumpallial muscular belt; *g*, *g*, marginal muscles; *h*, outer lamina of mantle, exhibiting through the inner homogeneous layer the bases of the cæca, *i*, *i*, and the reticulations of the external layer.

Fig. 7. Diagram of transverse section of a portion of the mantle:—*a*, outer lamina; *b*, external reticulated layer of ditto; *c*, homogeneous layer of ditto; *d*, bases of pallial cæca; *e*, inner lamina of mantle; *f*, epithelium of ditto; *g*, great pallial sinus; *h*, membranous lining of ditto; *i*, epithelium of ditto; *j*, genital organ; *k*, membrane with its epithelium coating ditto; *l*, membrane suspending genitalia; *m*, genital or pallial artery; *n*, outer pallial lacunes; *o*, inner ditto; *p*, lacunes connecting the latter with the genital artery.

Fig. 8. Portion of the extreme pallial margin, exhibiting pallial cæca in various stages of growth:—*a*, pallial membrane; *b*, clear spots, apparently corresponding to the bases of the testaceous prisms; *c*, *c*, enlarged portions of cæca; *d*, slender, duct-like portions of ditto; *e*, marginal fold.

Fig. 9. A branch of one of the hepatic lobes:—*a*, duct, exhibiting minute internal laminæ; *b*, terminal cæca.

Fig. 10. A ramuscule of the same branch a little enlarged:—*a*, duct; *b*, *b*, cæca.

PLATE LIX.

Fig. 1. External view of lateral half of the dorsal pallial lobe of *W. australis*, exhibiting the blood-lacunes:—*a*, *a*, anterior and lateral margins of lobe, armed with setæ; *b*, *b*, great pallial sinuses laid open; *c*, *c*, portions of the genitalia;

d, pallial or genital artery cut through; *e*, *e*, membrane along which the artery runs, and which suspends the genitalia; *f*, a similar membrane, probably also connected with an artery; *g*, *g*, nodules of reddish coloured matter attached to ditto, resembling that in connexion with the genitalia; *h*, *h*, *h*, nerves; *i*, portion of epithelium covering inner surface of mantle; *j*, external homogeneous layer, which, together with its epithelium, forms the inner pallial lamina; *k*, *k*, membrane lining the great sinus; *l*, portion of epithelial lining of sinus left adhering to the inner wall; *m*, *m*, *m*, external lamina of lobe; *n*, outer reticulated layer of ditto; *o*, *o*, *o*, blood-lacunes, forming the outer pallial lacunary system; *p*, *p*, points of union of the two layers between which the lacunes are situated; *q*, *q*, inner pallial lacunes or blood-channels communicating with the genital arteries, through the suspending membrane, and with the outer pallial lacunes; *r*, circumpallial vessel.

Fig. 2. Portion of the great brachial canal laid open, exhibiting the blood-channels or lacunes in its walls:—*a*, semi-cartilaginous or grooved ridge bearing the cirri, *b*, and the brachial fold, *c*; *d*, portion of stout membrane uniting the spirals; *e*, supposed afferent brachial channel; *f*, plexus of lacunes communicating with ditto, and probably with great brachial plexus; *g*, minute plexus at the point of union between the channels, *h*, that encircle the arm and those in the membrane connecting the spirals; *h'*, plexus situated at the other extremity of the encircling channels, and communicating with those of the grooved ridge or great brachial plexus, *i*; *j*, transverse channels of great brachial plexus; *k*, afferent brachial arteries; *l*, *l*, ditto entering cirri; *m*, orifices leading into cirri; *n*, *n*, wall of small or efferent brachial canal cut through and laid back.

Fig. 3. Portion of dorsal wall of the perivisceral chamber, the inner surface turned up, and the epithelium removed:—*a*, granular lining membrane; *b*, external reticulated layer, in which the pallial cæca originate; *c*, delicate homogeneous layer in contact with ditto; *d*, *d*, bases of pallial cæca; *e*, *e*, blood-channels or lacunes charged with blood-corpuscles and cellular tissue; *f*, contents of blood-channels left adhering to the homogeneous layer on removing the lining membrane.

Fig. 4. Portion of the external reticulated and homogeneous layers much magnified:—*a*, outer reticulated layer; *b*, homogeneous ditto; *c*, *c*, bases of the pallial cæca.

PLATE LX.

Fig. 1. Dorsal view of the animal of *Rhynchonella psittacea*:—*a*, pallial lobe; *b*, body; *c*, peduncle; *d*, *d*, great pallial sinuses giving branches of the margin; *e*, marginal fold; *f*, circumpallial vessel; *g*, extreme pallial margin; *h*, *h*, genitalia; *i*, *i*, muscular ties uniting the walls of the genital sinuses; *j*, *j*, brachial apparatus

appearing through the mantle; *k*, two lobes of the ventral surface corresponding to cavities at the sides of the foramen; *l*, two depressions occasioned by the bases of the crural processes or oral laminæ; *m*, *m*, extremities of anterior and posterior occlusors; *n*, liver; *o*, longitudinal depression for the reception of the dorsal septum; *p*, ridge formed by the union of the pallial margins.

Fig. 2. Ventral view of the same; the letters up to *j* agree with those of fig. 1:—*k*, bulbous extremity of intestine seen through the wall of the body; *l*, edge of the ventral mesentery; *m*, extremities of occlusor muscles; *n*, ditto of divaricators; *o*, ditto of accessory divaricators; *p*, ditto of ventral adjustors; *q*, *q*, ditto of peduncular muscles; *r*, peduncular nerves; *s*, two lobes corresponding to cavities at the sides of the foramen.

Fig. 3. View of pallial chamber of the same, the ventral pallial lobe turned back:—*a*, dorsal pallial lobe; *b*, ventral ditto; *c*, *c*, great pallial sinuses giving branches to the margin; *d*, *d*, genitalia; *e*, *e*, muscular ties passing between the walls of the sinuses; *f*, base of the membrane suspending the genitalia, forming a reticulated line; *g*, circumpallial vessel; *h*, marginal fold; *i*, anterior margin of divaricators; *j*, occlusors; *k*, ventral oviducts; *l*, external orifices leading into ditto; *m*, brachial apparatus; *n*, brachial fold; *o*, position of the mouth concealed by ditto; *p*, cirri, contracted and curled; *q*, œsophagus.

Fig. 4. Portion of the alimentary canal:—*a*, stomach; *b*, intestine; *c*, lower, imperforate, bulbous extremity of ditto; *d*, hepatic ducts; *e*, dorsal mesentery; *f*, gastro-parietal bands; *g*, central band; *h*, ilio-parietal bands; *i*, laminated portions of oviducts; *j*, heart in contracted state; *k*, branchio-systemic vein; *l*, aorta; *m*, ventral pallial arteries.

Fig. 5. Intestine of another specimen:—*a*, imperforate bulbous extremity, the longitudinal plications of the mucous membrane appearing through the walls; *b*, a transparent line or ridge corresponding to a groove in the mucous membrane; *c*, ventral mesentery; *d*, portions of ilio-parietal bands.

Fig. 6. Transverse section of intestine:—*a*, muscular wall, the external sheath is not represented; *b*, mucous membrane, exhibiting large, longitudinal plicæ; *c*, longitudinal transparent line; *d*, ventral mesentery.

Fig. 7. Oviduct as appearing from the perivisceral chamber:—*a*, laminated portion, opening into the perivisceral chamber; *b*, tubular portion; *c*, wrinkles of the lining membrane appearing through the surface; *d*, apex opening externally; *e*, accessory pulsatile vesicle; *f*, genital artery; *g*, ditto, following the reticulations of the suspending membrane.

Fig. 8. Transverse section of tubular portion of oviduct:—*a*, lining membrane.

Fig. 9. Transverse section of arm:—*a*, wall of the great brachial canal; *b*, thickened portion of ditto; *c*, grooved ridge; *d*, brachial fold; *e*, roots of cirri; *f*, expanded orifices of ditto, opening into the efferent brachial canal, *g*.

Fig. 10. Base of one of the arms laid open, exposing the inner surface of the great

brachial canal:—*a*, *a*, walls of ditto; *b*, grooved ridge; *c*, brachial fold; *d*, cirri; *e*, efferent brachial canal, the orifices leading into the cirri appearing through its wall in a double series; *f*, afferent brachial channel, charged with coagulated pellets of blood-corpuscles.

Fig. 11. Pellets of coagulated blood-corpuscles from the tissue of the brachial grooved ridge.

Fig. 12. One of the smaller spicula from the mantle of *T. caput-serpentis*.

PLATE LXI.

Fig. 1. General view of the viscera of *Rhynchonella psittacea*, seen from behind, the umbonal portions having been removed:—*a*, dorsal pallial lobe; *b*, ventral ditto; *c*, *c*, anterior wall of perivisceral chamber; *d*, *d*, anterior occlusor muscles; *d'*, *d'*, posterior ditto; *e*, *e*, ventral extremities of divaricators; *f*, *f*, ditto of ventral adjustors; *g*, portion of the œsophagus; *h*, stomach, exhibiting two of the orifices of the hepatic ducts, the left lobes of the liver having been removed; *i*, right anterior and posterior hepatic lobes; *j*, intestine; *k*, bulbous termination of ditto; *l*, dorsal mesentery; *m*, portion of ventral ditto; *n*, *n*, lateral gastro-parietal bands; *o*, central gastro-parietal band; *p*, *p*, ilio-parietal bands; *q*, heart in contracted state; *r*, aorta, giving off two lateral branches; *s*, *s*, dorsal pallial or genital arteries; *t*, *t*, ventral ditto; *u*, *u*, *u*, *u*, pulsatile vesicles in connexion with the pallial arteries; *v*, *v*, *v*, *v*, dorsal and ventral pairs of oviducts; *w*, *w*, *w*, *w*, genital organs lying within the pallial sinuses; *x*, *x*, muscular bands or ties passing between the walls of the sinuses; *y*, sheaths of the crural processes or oral laminæ; *z*, orifices leading into ditto; *z'*, portions of the dorsal adjustor muscles.

Fig. 2. Side view of the viscera of the same:—*a*, anterior wall of perivisceral chamber; *b*, *b*, brachial organs; *c*, ventral terminations of occlusor muscles; *c'*, *c'*, dorsal terminations of anterior and posterior occlusors; *d*, *d*, divaricators, the left one cut through; *d'*, ventral wall of perivisceral chamber; *e*, peduncle; *e'*, capsule of ditto; *f*, peduncular muscle; *g*, one of the dorsal adjustors; *h*, one of the ventral ditto; *i*, œsophagus; *j*, stomach, exhibiting the two openings of the left hepatic ducts, the liver having been removed from this side; *k*, right lobes of the liver; *k'*, posterior lobe; *k''*, anterior ditto; *l*, dorsal mesenteric membrane; *m*, *m*, ventral ditto; *n*, lateral gastro-parietal band; *o*, central ditto; *p*, *p*, ilio-parietal bands; *q*, heart; *r*, branchio-systemic vein; *s*, aorta; *t*, *t'*, dorsal and ventral pallial or genital arteries; *u*, right ventral oviduct; *u'*, portion of left ditto cut through; *v*, œsophageal ganglia; *w*, sheath of crural process or oral lamina; *x*, orifice leading into ditto; *y*, portion of ditto of the opposite side; *z*, terminal sac of the left great brachial canal; *z'*, ditto of the right or opposite arm, seen through the mesenteric membrane.

Fig. 3. Side view of the stomach and liver:—*a*, cardiac extremity of stomach; *b*, pyloric ditto; *c*, transverse ridge, to which the gastro-parietal bands are attached; *d*, *d*, hepatic ducts; *e*, *e*, branched cæca composing the liver.

Fig. 4. Stomach laid open:—*a*, œsophagus; *b*, intestine; *c*, *c*, folds of the lining membrane; *d*, *d*, orifices of hepatic ducts; *e*, groove corresponding to the external transverse ridge.

Fig. 5. Portion of epithelium from the mantle of *W. australis*, much magnified.

Fig. 6. Portion of epithelium lining the great brachial canal.

PLATE LXII.

Fig. 1. Diagram of the muscular system of *W. australis*:—*a*, dorsal valve; *b*, ventral ditto; *c*, peduncle; *d*, capsule of ditto; *e*, calcareous loop; *f*, hinge-plate; *g*, alimentary tube; *h*, heart; *i*, anterior occlusors; *j*, posterior ditto; *k*, divaricators; *l*, accessory ditto; *m*, dorsal adjustors; *n*, ventral ditto; *o*, peduncular muscle; *p*, cardinal process.

Fig. 2. Diagram exhibiting muscular arrangement of *W. cranium*:—*a*, dorsal valve; *b*, ventral ditto; *c*, peduncle; *d*, capsule of ditto; *e*, calcareous loop; *f*, dental socket; *g*, *g*, anterior and posterior occlusors of the right side, those of the left having been removed; *h*, *h*, areas of attachment of dorsal extremities of the left occlusors; *i*, *i*, divaricators and their accessories combined; *j*, ventral adjustors; *k*, *k*, dorsal ditto; *l*, peduncular muscle; *m*, cardinal process.

Fig. 3. Diagram of the muscular system of *Lingula anatina*:—*a*, dorsal valve; *b*, ventral ditto; *c*, *c*, alimentary tube, the convoluted portion of intestine removed; *d*, heart; *e*, *e*, a double line, indicating the margin of the lateral and anterior walls of the perivisceral chamber; *f*, area of attachment of the posterior parietal muscles; *g*, anterior occlusors; *h*, posterior ditto; *i*, divaricators; *j*, central adjustors; *k*, external ditto; *l*, *l*, *l*, posterior ditto; *m*, muscular cylinder of peduncle deprived of its horny sheath; *n*, peduncular muscle.

Fig. 4. Divaricator muscles of variety of *W. australis*, showing them combined with their accessories:—*a*, portion of peduncular capsule; *b*, peduncular muscle; *c*, portion of ventral adjustor; *d*, portion of dorsal ditto; *e*, portion of occlusors; *f*, divaricators; *g*, portion of ditto, corresponding to the accessory divaricators; *h*, extremities attached to cardinal process.

Fig. 5. Ventral extremity of anterior occlusor of *W. australis*:—*a*, fleshy contractile portion; *b*, *b*, white tendinous ditto.

Fig. 6. A little of the fleshy portion of the posterior occlusor, much magnified, exhibiting transverse striæ.

Fig. 7. A fibre and two fibrillæ of same, more highly magnified:—*a*, fibre; *b*, *b*, fibrillæ, exhibiting cell-like structure.

Fig. 8. A little of the fleshy portion of one of the non-striated muscles, much magnified.

Fig. 9. A fibre and a few of the fibrillæ of the same, greatly magnified:—*a*, fibre; *b*, *b*, fibrillæ.

Fig. 10. Transverse section of peduncle of *Lingula anatina*:—*a*, central channel; *b*, muscular cylinder, exhibiting radiating divisions; *c*, external horny sheath.

Fig. 11. Œsophageal ganglia of *W. australis*:—*a*, central or anterior ganglion; *b*, *b*, lateral or posterior ganglia; *c*, labial ditto; *d*, commissure completing œsophageal collar; *e*, a pair of minute ganglia giving filaments apparently to œsophagus; *f*, dorsal pallial nerve; *g*, *g*, *g*, nerves supplying anterior wall of perivisceral chamber; *h*, two nerves supplying dorsal adjustor muscles; *i*, *i*, ventral pallial nerves; *i'*, *i'* branches of ditto; *j*, peduncular ditto; *k*, brachial nerves.

Fig. 12. Œsophageal ganglia of *W. cranium*, seen from above; the letters correspond to those of fig. 11:—*l*, bundle of muscular fibres. The brachial nerves are not displayed.

Fig. 13. View of the under side of the same ganglia: letters as in fig. 11.

Fig. 14. View of the loop of the dorsal pallial nerve:—*a*, anterior occlusor; *b*, posterior ditto; *c*, pallial nerve; *d*, loop of ditto; *e*, *e*, branches supplying muscles; *f*, *f*, ditto supplying pallial lobe.

Fig. 15. The same, more enlarged:—*a*, posterior occlusor; *b*, loop; *c*, *c*, *c*, *c*, nerves supplying muscle; *d*, pallial nerve.

PLATE LXIII.

Fig. 1. Diagram exhibiting central portion of vascular system of *W. australis*:—*a*, portion of dorsal pallial lobe; *b*, ventral ditto; *c*, *c*, anterior wall of perivisceral chamber; *d*, *d*, areas of attachment of anterior and posterior occlusors; *e*, ditto, of ventral extremities of ditto; *f*, *f*, ditto of divaricators; *g*, *g*, ditto of ventral adjustors; *h*, *h*, ditto of accessory divaricators; *i*, *i*, peduncular muscle; *j*, peduncular capsule; *k*, peduncle; *l*, alimentary tube; *m*, *m*, gastro-parietal bands; *n*, *n*, ilio-parietal bands; *o*, orifice leading into oviduct; *p*, heart; *q*, branchio-systemic vein; *r*, aorta; *s*, *s*, dorsal pallial or genital arteries; *t*, *t*, ventral ditto; *u*, *u*, *u*, *u*, accessory pulsatile vesicles.

Fig. 2. Diagram of the nervous system of the same; the letters up to *k* correspond to those of fig. 1:—*l*, *l*, *l*, genitalia; *m*, root of œsophagus; *n*, anterior or central œsophageal ganglion; *o*, *o*, posterior or lateral ganglia; *p*, collar; *q*, *q*, labial ganglia; *r*, *r*, dorsal pallial nerves; *s*, *s*, *s*, branches of ditto to pallial lobe; *t*, loop of pallial nerve, giving off numerous minute twigs to occlusor muscles; *u*, *u*, *u*, ventral pallial nerves; *v*, *v*, posterior or peduncular nerves; *w*, peduncular branches of ditto; *x*, capsular branches of ditto; *y*, parietal branch of ditto; *z*, nerves to anterior wall of perivisceral chamber; *z'*, *z'*, two nerves to dorsal adjustor muscles.

Fig. 3. Accessory pulsatile vesicle of the ventral pallial artery:—*a*, artery; *b*, *b*, pallial branches of ditto; *c*, vesicle.

Fig. 4. Ventral pallial artery, with two pulsatile vesicles attached:—*a*, artery; *b*, pallial branches of ditto; *c*, pulsatile vesicle; *d*, supplementary ditto.

PLATE LXIV.

Fig. 1. Dorsal view of the animal of *Lingula anatina*, the shell having been removed:—*a*, pallial lobe; *b*, body; *c*, great pallial sinuses; *d*, a white line running along the outer wall of ditto, function unknown; *e*, *e*, orifices, seen through the pallial membrane, leading into the lateral branches of the sinuses; *f*, central branches of ditto; *g*, posterior branches of ditto; *h*, *h*, ramuscules of posterior branches; *i*, marginal fold; *j*, extreme pallial margin; *k*, setæ; *l*, *l*, liver, seen through the wall of the perivisceral chamber; *m*, portion of intestine; *n*, dorsal ovaries; *o*, *o*, testis; *p*, extremities of anterior occlusor muscles; *q*, ditto of posterior occlusors; *r*, ditto of central adjustors; *s*, ditto of external adjustors; *t*, ditto of posterior adjustors; *u*, ditto of divaricators; *v*, ditto of posterior parietals; *w*, edge of the lateral and anterior walls of the body.

Fig. 2. Ventral view of the same; the letters as in fig. 1:—*x*, extremity of peduncular muscle; *y*, oviducts.

Fig. 3. View of the pallial chamber of the same, the ventral pallial lobe turned back:—*a*, ventral lobe; *b*, dorsal ditto; *c*, *c*, great pallial sinuses; *d*, *d*, lateral branches of ditto; *e*, *e*, puckers of lateral branches, occasioned by contraction of the pallial margin; *f*, *f*, terminal extremities of lateral branches; *g*, *g*, central branches of the great sinuses; *h*, marginal fold; *i*, a few of the setæ; *j*, extreme pallial margin; *k*, brachial apparatus; *l*, *l*, cirri; *m*, brachial fold; *n*, mouth; *o*, *o*, external orifices of oviducts.

Fig. 4. Dorsal view of the viscera of a young individual of *L. anatina*, the perivisceral chamber laid open:—*a*, *a*, great pallial sinuses; *b*, openings of ditto into the perivisceral chamber; *c*, posterior branches of ditto; *d*, anterior occlusors; *e*, posterior ditto; *f*, central adjustors; *g*, external ditto; *h*, *h*, posterior ditto; *i*, divaricators; *j*, posterior parietals; *k*, *k*, anterior and lateral walls of the perivisceral chamber; *l*, œsophagus; *m*, stomach; *n*, straight portion of intestine; *o*, convoluted portion of ditto; *p*, *p*, hepatic ducts, the dorsal lobes of the liver having been removed; *q*, dorsal ovaries; *r*, ilio-parietal bands; *s*, gastro-parietal ditto; *t*, heart, contracted; *u*, branchio-systemic vein; *v*, aorta, giving off two lateral trunks, which divide into anterior and posterior branches; *w*, external arteries or blood-channels,—nerves of Owen,—supplying anterior wall of the perivisceral chamber; *x*, internal ditto.

Fig. 5. Ventral view of the viscera of the same; the letters up to *k* correspond to those

of fig. 4:—*l*, peduncular muscle; *m*, portion of intestine; *n*, ventral lobe of liver; *o*, *o*, *o*, ventral ovaries; *p*, tubular portion of oviducts.

Fig. 6. Transverse section of straight portion of intestine:—*a*, membranous sheath; *b*, muscular wall; *c*, mucous membrane; *d*, *d*, portions of ilio-parietal bands; *e*, transparent line corresponding to groove in mucous membrane.

Fig. 7. A small portion of the intestine laid open, exhibiting the plicæ of the mucous membrane:—*a*, *a*, transverse plicæ.

PLATE LXV.

Fig. 1. Dorsal view of the perivisceral chamber of young specimen of *L. anatina*, most of the muscles, the liver and genitalia having been removed:—*a*, dorsal extremities of anterior occlusors; *b*, ditto of divaricators; *c*, *c*, anterior parietals; *d*, posterior ditto; *e*, *e*, anterior and lateral walls of chamber; *f*, œsophagus; *g*, stomach; *h*, straight portion of intestine; *i*, transparent line or ridge; *j*, convoluted portion of intestine; *k*, *k*, *k*, hepatic ducts; *l*, gastro-parietal bands; *m*, muscles attaching ditto to valve; *n*, ilio-parietal bands; *o*, margin of ditto, extending along oviducts; *p*, heart, contracted; *q*, aorta; *r*, posterior artery; *s*, anterior ditto; *t*, oviducts,—the so-called hearts; *u*, laminated portion of ditto, that on the left side has the margin turned back; *v*, orifice leading into oviduct.

Fig. 2. Dorsal view of the muscular system of the same, all the viscera having been removed:—*a*, posterior parietal muscles; *b*, anterior ditto; *c*, *c*, lateral and anterior walls of the perivisceral chamber; *d*, muscles supporting the gastro-parietal bands; *e*, anterior occlusors; *f*, posterior ditto; *g*, divaricators; *h*, central adjustors; *i*, *i*, external ditto; *j*, *j*, *j*, posterior ditto; *k*, external arteries or blood-channels; the dotted lines mark their path through the muscles; *l*, internal ditto.

Fig. 3. Dorsal view of the viscera of *L. affinis*, the dorsal hepatic lobes and ovaries having been removed:—*a*, anterior occlusors; *b*, posterior ditto; *c*, divaricators; *d*, central adjustors; *e*, external ditto; *f*, *f*, *f*, posterior ditto; *g*, posterior parietals; *h*, *h*, margins of the lateral and anterior walls of the perivisceral chamber; *i*, *i*, ventral ovaries; *j*, œsophagus; *k*, stomach; *l*, straight portion of intestine, exhibiting longitudinal ridge; *m*, convoluted portion of intestine; *n*, terminal portion, or rectum; *o*, membrane uniting ditto to the wall of the perivisceral chamber; *p*, heart in contracted state; *q*, branchio-systemic vein; *r*, aorta; *s*, gastro-parietal bands; *t*, muscles supporting ditto; *u*, ilio-parietal bands; *v*, external blood-channels or arteries.

Fig. 4. Lateral view of alimentary canal:—*a*, mouth; *b*, œsophagus; *c*, stomach; *d*, straight portion of intestine, exhibiting longitudinal ridge; *e*, convoluted portion of ditto; *f*, terminal portion of ditto; *g*, anus; *h*, *h*, hepatic ducts;

i, dorsal mesentery; *j*, *j*, portions of gastro-parietal bands; *k*, ilio-parietal ditto; *l*, heart in contracted state; *m*, branchio-systemic vein; *n*, enlarged portion of ditto; *o*, aorta; *p*, one of the lateral branches of ditto, dividing into anterior, *q*, and posterior, *r*, arteries; *s*, lateral œsophageal membrane.

Fig. 5. Portion of branchio-systemic vein, as seen in the compressor:—*a*, outer envelope or sheath; *b*, delicate internal tunic; *c*, fold or wrinkle of ditto.

Fig. 6. Transverse section of arm:—*a*, anterior or great brachial canal; *b*, posterior ditto; *c*, *c*, longitudinal muscle situated in ditto; *d*, small or efferent canal; *e*, grooved ridge; *f*, bases of cirri; *g*, brachial fold; *h*, blood-channels in ditto; *i*, *i*, epithelium; *j*, *j*, thickened cartilage-like portions of the walls of the brachial canals.

Fig. 7. Transverse section of arm of *L. anatina*; the letters correspond to those of fig. 6.

Fig. 8. Transverse section of grooved ridge:—*a*, brachial fold; *b*, *b*, bases of cirri; *c*, small or efferent brachial canal; *d*, orifices leading from ditto into cirri; *e*, blood-channels; *f*, *f*, *f*, *f*, muscular bands for the movements of the parts; *g*, anterior or great brachial canal; *h*, posterior ditto; *i*, *i*, epithelium.

Fig. 9. Corpuscles found in the pallial membranes of *W. australis*, supposed to be muscular.

PLATE LXVI.

Fig. 1. Dorsal view of the animal of *L. affinis*, the perivisceral chamber partially laid open:—*a*, pallial lobe; *b*, great pallial sinuses; *c*, a white line running along the outer wall of ditto; *d*, *d*, outer or lateral branches of sinuses, exhibiting a similar white line, *e*, in their external wall; *f*, *f*, central branches of sinuses; *g*, posterior branches of ditto; *h*, ramuscules of posterior branches; *i*, marginal fold; *j*, extreme pallial margin; the setæ are not represented; *k*, *k*, *k*, liver, a portion of which is removed to expose the heart, *l*; *m*, portion of alimentary canal; *n*, *n*, dorsal ovaries; *o*, *o*, two coils of the intestine seen through the wall of the perivisceral chamber; *p*, extremities of anterior occlusors; *q*, ditto of posterior ditto; *r*, ditto of central adjustors; *s*, ditto of external adjustors; *t*, ditto of posterior adjustors; *u*, ditto of divaricators; *v*, ditto of posterior parietals; *w*, *w*, margins of lateral and anterior walls of the perivisceral chamber.

Fig. 2. Ventral view of the same, the pallial lobe, *a*, turned back to expose the pallial chamber; *b*, dorsal pallial lobe; *c*, great pallial sinuses; *d*, *d*, outer or lateral branches of ditto; *e*, inner branches of ditto; *f*, ramuscules of posterior branches of ditto; *g*, extremity of peduncular muscle; *h*, marginal fold; *i*, extreme pallial margin; *j*, marginal setæ; *k*, *k*, attenuated cæcal extremities of the lateral pallial sinuses; *l*, brachial apparatus; *m*, cirri; *n*, *n*, brachial fold; *o*, mouth partially concealed by ditto.

Fig. 3. Side view of the same; the dorsal pallial lobe divided longitudinally, and one half of it turned back, so as to expose the pallial chamber; the marginal setæ are not represented:—*a*, *a*, pallial sinuses; *b*, marginal fold; *c*, liver seen through the wall of the perivisceral chamber; *d*, dorsal ovaries; *e*, *e*, intestine; *f*, lateral wall of the body, or perivisceral chamber; *g*, anal nipple; *h*, brachial apparatus; *i*, cirri; *j*, adjustor muscles; *k*, divaricators; *l*, anterior wall of body.

Fig. 4. View of the walls of the perivisceral chamber of *L. anatina*:—*a*, posterior parietal muscles; *b*, anterior ditto; *c*, muscular lining of anterior wall; *d*, muscles in connexion with the gastro-parietal bands; *e*, divaricators; *f*, root of œsophagus; *g*, fold of anterior wall to which the occlusors are adherent; *h*, two orifices leading from the perivisceral chamber to a cavity situated between the bases of the arms; *i*, external arteries or blood-channels entering anterior wall.

Fig. 5. Transverse section of pallial lobe of the same:—*a*, marginal fold; *b*, one of the setæ; *c*, extreme pallial margin; *d*, circumpallial lacune; *e*, *e*, peripheral or outer pallial lacunes; *f*, ties binding the walls of ditto together; *g*, *g*, channels of the lateral branches of the great pallial sinus; *h*, channels of intermediate small branches of ditto.

Fig. 6. Proximal extremity of peduncle:—*a*, horny sheath; *b*, muscular cylinder seen through ditto; *c*, extremity of muscular cylinder or peduncular muscle; *d*, triangular process of horny sheath, fitting into a corresponding depression in the umbo of the ventral valve.

Fig. 7. The same extremity of peduncle, with the horny sheath laid open:—*a*, horny sheath; *b*, muscular cylinder; *c*, *c*, delicate membrane coating ditto.

Fig. 8. Portion of the wall of the perivisceral chamber, with part of the testis adhering:—*a*, wall of chamber; *b*, testis, exhibiting spermatophora in various stages of development.

Fig. 9. Three spermatophora, highly magnified:—*a*, *a*, two of ditto, apparently fully developed, containing spermatozoa; *b*, one, immature, exhibiting a double line in the interior.

Fig. 10. Two spermatophora, in an early state of development.

XXXV. *On* Chondrosteus, *an Extinct Genus of the Sturionidæ, found in the Lias Formation at Lyme Regis. By Sir* Philip de Malpas Grey Egerton, *Bart., M.P., F.R.S., F.G.S. &c.*

Received April 20,—Read May 6, 1858.

Genus CHONDROSTEUS, Agassiz.

(Subkingdom Vertebrata, Class Pisces, Order Goniolepidoti, Family Sturionidæ.)

Head covered with bony plates. Body short, deep, adpressed, devoid of dermal plates. Scapula and coracoid united. Dorsal fin advanced. Tail heterocerque. Fin-rays formula: P. 50; V. 50; D. 75; A. 30; C. 75. Endoskeleton partly ossified, partly cartilaginous.

The recognition of a member of the Sturgeon family in the fossil state is due to Professor Agassiz, whose quick perception detected in some fragmentary specimens, found in the lias shales at Lyme Regis, structural peculiarities which convinced him that this family was not unrepresented in the secondary strata of Great Britain. The specimens first discovered were portions of the caudal fin, and it was from the examination of these that he established the genus *Chondrosteus*, and determined its affinities to the Sturgeons. This result is noticed at page 280 of the 2nd part of the 2nd volume of the 'Poissons Fossiles,' but no description is there given; nor has the subject been since alluded to by the Professor, the engagements undertaken in the United States having put a stop to the preparation of the supplementary continuation of his great work on which he was engaged previous to his departure. Most of the specimens subsequently discovered appertain also to the caudal region. The massive proportions of the caudal fin, the strength of the fin-rays, and the thickness and hardness of the fulcral scales on the upper lobe, account for the preservation of these parts in more perfect condition than others less qualified to resist the destructive agencies to which they have been exposed. Recent discoveries have disclosed a chain of evidence connecting these specimens with others, some of which were formerly assigned to the Sauroid and Cœlacanthoid families. The first link was afforded by a specimen which, in addition to the lower lobe of the caudal fin, contained the anal fin; subsequently a specimen came to light having the ventral fins superadded to the anal and caudal fins; and lastly, a fine example in hard lias, showing the posterior part of the cranium, both pectoral fins, both ventral fins, the dorsal fin and the anal fin (Plate LXVII.). The snout and the tail are deficient. The study of this specimen, and more especially of the scapulocoracoid arch and its appendages, led to the identification of many other specimens of the anterior parts which were not before supposed to have belonged to this genus. The facts brought to

light by these discoveries, and the more extended observations based thereupon, fully corroborate the conclusion arrived at by Professor AGASSIZ, that this genus, although differing generically from the Sturgeons of the present epoch, belonged, nevertheless, to the same family. These facts I now proceed to particularize in detail, commencing with a general description of the most perfect specimen, and proceeding step by step through the anatomical characters displayed in the several specimens I have examined, so far as their state of preservation will allow.

The most perfect specimen yet discovered (Plate LXVII.) is contained in a nodule of indurated lias. The rostral and caudal extremities are deficient, and it is otherwise much injured by the attempts to relieve it from the matrix in which it is imbedded. Excluding what remains of the head, and measuring from the articulation of the pectoral fin with the scapulocoracoid arch to the hinder margin of the anal fin, the length of the trunk is 15 inches. The greatest vertical depth is immediately in front of the dorsal fin, where it measures 6 inches. In a recent Sturgeon having the same longitudinal dimensions, the greatest vertical depth is only 3 inches, or in proportion to the length as 1 to 5, the relative proportions in the fossil being as 2 to 5. The comparative measurements are more disproportionate when applied to a restoration of the fossil genus. By selecting from the numerous specimens which have been found, a tail of a size corresponding with the other parts of the individual under description, and adjusting it thereto, the additional length obtained is 9 inches, making a total length of 24 inches from the attachment of the pectoral fin to the extremity of the upper lobe of the tail. The measurement of the corresponding part in the recent Sturgeon gives an increase of $7\frac{1}{2}$ inches, or a total length of $22\frac{1}{2}$ inches; the result being that the proportion of depth to length in the fossil is as 1 to 4, and in the recent fish as 1 to $7\frac{1}{2}$. The vertical diameter of the fossil at the point of fracture behind the anal fin is $4\frac{1}{2}$ inches, the corresponding measurement of the recent fish is only 1 inch. It will be apparent from these dimensions that the Sturgeon of the lias differs from the existing Sturgeons in having a shorter and more bulky body, deepest in its middle portion, and contracting very gradually posteriorly as far as the anal fin. It is shown by other specimens that the diminution of bulk behind this point was more rapid down to the point whence the caudal fin expands. The breadth of the body was not, as it is in the Sturgeon of the present day, commensurate with the depth; for it is evident, from the proximity of the pectoral and ventral fins of either side to their fellows, that the sides of the fish were more flattened, and that the horizontal diameter of the body was considerably less than the vertical one. However striking and distinctive these proportions may be, compared with the graceful and taper outlines of the recent Sturgeons, other characters are afforded by the structure, form and position of the natatory organs, equally corroborative of generic difference.

The fins in all the recent Sturgeons are thus arranged:—the ventral fins are situated at the commencement of the posterior third segment of the body; the anal fin occupies a median position between these fins and the lobe of the tail, whilst the dorsal

fin is placed above the anal fin, having its anterior rays a little in advance of the first rays of that fin. In *Chondrosteus* the ventral fins are found midway between the pectoral fins and the tail; the dorsal fin is immediately above the ventral fins, and the anal fin approximated to the lower lobe of the tail. As regards size, all the fins are proportionately larger than those of the existing Sturgeons, as might naturally be inferred from the greater bulk of the fish. In proceeding to give a detailed description of the organs of locomotion and their associated parts, I commence with the bony framework which affords attachment and support to the pectoral fins; premising that the letters and numbers by which the several parts are designated on the drawings are those employed by Professor OWEN in his tabular notation of the homologies of the Vertebrate Skeleton.

Scapular Arch and its Appendages.—In the recent Sturgeons the strong bony girdle encircling the thoracic region of the trunk and providing a firm attachment for the large pectoral fins, is composed of three elements on either side, the suprascapular, the scapular, and the coracoid. In the extinct genus this number is reduced to two by the coalescence of the two latter to form a single bone (Plates LXVIII. fig. 1, and LXIX. 51, 52). This scapulocoracoid bone, from its size and comparative hardness, is more frequently preserved and more perfectly displayed than any other of the constituent parts of the cranial framework. The external portion is crescentic, the concavity being anterior for the reception of the posterior margin of the opercular flap. At the point of attachment of the pectoral fin the bone is thick and rounded; the upper or scapular portion expands gradually into a triangular plate, thinning off towards the upper extremity for adjustment with the suprascapular bone; the lower or coracoid portion also expands as it descends, sweeping under the thorax and meeting the corresponding bone of the opposite side on the median line. The exposed surfaces of these bones are prettily ornamented with sharp undulating asperities, not unlike the surface ornament of the shell of *Pholas crispata*. Anteriorly each scapulocoracoid expands into a broad concave plate, directed inwards and forming the platform of the branchial cavity, and partitioning it off from the thoracic cavity. This portion of the bone has the surface perfectly smooth. The upper or suprascapular member of the arch (Plate LXIX. 56) overlaps the extremity of the scapulocoracoid bone, and extends thence to the occipital region of the skull. It is of slender dimensions compared with the homologous bone of the recent Sturgeons. The ornamentation characteristic of the external portion of the scapulocoracoid bones is continued along the anterior margin of the suprascapular, but the greater portion of the bone seems to have been invested with the dermal integument; in this respect corresponding with the homologous bone in the ordinary ganoid fishes. The pectoral fins (Plates LXVII., LXVIII. fig. 1, and LXIX. P) are attached to the scapulocoracoids immediately behind the posterior angles of these bones. They are proportionately much broader and more rounded at their extremities than these organs of the recent Sturgeon, but the anterior ray is not nearly so strong. They have no representatives of radius, ulna, or carpus, but the fin-rays are articulated to a series of strong metacarpal bones, of which

those supporting the hinder rays are the longest (Plate LXIX. *sr*). Each metacarpal bone seems to have given attachment to several of the rays. The first ray is more massive than the succeeding ones, and is considerably shorter. It appears to be formed by the coalescence of two or more rays, and is subject to variations in this respect consequent, it may be, on the age of the individual. The surface is corrugated at the base and longitudinally sulcated above. The succeeding rays are about fifty in number. The anterior ones increase successively in length as they recede from the first or principal ray as far as the seventh or eighth ray, at which point the maximum extent of the fin is attained; and hence the fin-rays decrease gradually to the hinder margin of the fin. A few of the last rays lose their round character and become broad and inflexible triangular plates attached by their apices, and dilated posteriorly towards their distal extremities. The principal rays continue single for a considerable distance from the metacarpus, without either bifurcations or transverse joints; but in the more remote portions of the organ dichotomizations and joints are very numerous. In all the other fins the transverse articulations are continued to the base of the rays. The surface of the pectoral fin is irregularly beset with small asperities, a character which serves to distinguish a mere fragment of this fin from that of any other fossil fish with which I am acquainted. The dimensions of this fin, compared with the pectoral fin of the recent specimen already referred to in the other measurements, are as follows:—Recent Sturgeon 3 inches long by $1\frac{1}{2}$ wide; Fossil, $5\frac{1}{2}$ inches long by $3\frac{1}{2}$ wide. The interval between the fins is 3 inches in the recent and 4 inches in the fossil fish, from the innermost rays of one fin to the corresponding rays of the other.

Ventral Fins (Plate LXVII. V).—No traces of pubic bones have as yet been found in the specimens I have examined, but in one where the base of the ventral fin is preserved, the constituent fin-rays are seen to be attached to a series of short styliform ossicles. These tarso-metatarsal bones occur in the recent Sturgeon in a semicartilaginous condition, and in the Polypterus, but they are not found in the generality of recent osseous fishes. The ventral fin, when expanded, forms a nearly equilateral triangle, the sides of which measure about $2\frac{3}{4}$ inches each. It is composed of more than fifty rays. These increase gradually in length from the first to the twelfth, which is the longest. They are gracefully curved, and are frequently subdivided both longitudinally and transversely. The interval between the fins is 2 inches; in the recent specimen it is 1 inch.

Dorsal Fin (Plate LXVII. D).—The dorsal fin is situated about the middle of the back, immediately above the ventral fins, extending over a space of $4\frac{1}{2}$ inches, and measuring $3\frac{1}{2}$ inches in height. It contains between seventy and eighty rays. Of these a few of the anterior rays are short and single, representing the fulcral scales common to many genera of ganoid fishes. They are succeeded by thick, jointed rays, increasing successively in height as far as the fourteenth, and thence decreasing gradually to the posterior termination of the fin. The rays bifurcate at some distance from their bases, and are frequently subdivided as they recede from the body. The transverse joints

commence near the insertions of the rays, and are repeated at shorter intervals on the posterior parts of the fin. The form of the dorsal fin, when expanded, represents a right-angled triangle, the rectangle occupying the apex, and the posterior angle being rather more acute than the anterior one, if the fulcral rays are not taken into account. Compared with the homologous organ of the Sturgeon, it is remarkable for its greater proportional expansion and strength. The comparison with the recent specimen employed in all the comparative measurements, gives the dimensions of 2 inches by $1\frac{1}{2}$ inch for the Sturgeon, and $4\frac{1}{2}$ inches by $3\frac{1}{2}$ inches for the fossil. The former contains thirty-five rays, the latter probably eighty.

Anal Fin (Plates LXVII. and LXX. A).—The anal fin is placed nearer to the base of the caudal fin than to the ventral fins. It is the smallest of the natatory organs in the fossil genus, whereas the ventral fins are the smallest in the recent Sturgeon. The interhæmal spines supporting the fin are ten or twelve in number, elongated, slightly arched, and flattened at the articular extremities (Plate LXX. *i h*). The fin-rays are above thirty in number, and more slender than those of the dorsal fin. The lateral surfaces are subangular and not rounded, as in the dorsal and ventral fins. The transverse joints are frequent. The decrement in the length of the rays, from the anterior to the posterior limit of the fin, is very rapid, the posterior rays being short, slender, and finely fimbriate. The form of the fin is that of an isosceles triangle, broader at the base and less acute at the apex than the corresponding fin of the recent Sturgeon.

Caudal Fin (Plate LXX. C).—In all essential structural points the caudal fin of *Chondrosteus* corresponds closely with that of the recent Sturgeons. It differs, however, in form and relative proportions. It is considerably broader and more massive; the lobes are more divergent; the upper lobe is less acutely prolonged, and the lower one more nearly the length of the upper one. The point of divergence of the lobes is on a line with the axis of the body, so that the two halves are more symmetrical than in the tail of the Sturgeon. The upper border of the fin is composed of a single row of strong chevron-shaped fulcral scales, elongating in succession as they extend towards the extremity of the tail. These scales are imbricated, and each had a deep median sulcus at its base for the attachment of the preceding scale of the series. This portion of the caudal organ is further strengthened by a set of short spatulate neurapophyses (Plate LXX. C, *n a*), extending some distance into the lobe of the tail and supporting the ridge scales, but not giving attachment to any of the fin-rays. The lower lobe has a similar apparatus of hæmapophyses (Plate LXX. C, *h a*), considerably longer than the former. They afford attachment to a numerous group of interhæmal ossicles, having pointed bases and broad flattened extremities, to which the fin-rays are attached. The rays are from seventy to eighty in number. The inferior ones are the strongest, and they decrease in size as they succeed each other to the furthest extremity of the fin. The lower margin of the fin is destitute of fulcral scales, and is bounded by true fin-rays, elongating rapidly in succession until the maximum length of the lobe is attained. The bifurcations of the rays occur at very irregular intervals; they are more frequent in the

distal parts than in the vicinity of the base. The transverse joints are very frequent in all the rays. The upper lobe is invested, from the base to the extremity, with numerous rows of thick narrow imbricated scales, lozenge-shaped near the base, but elongating more and more until they become almost acicular at the distal termination of the fin. The pedicle of the tail is robust, in proportion to the length and spread of the organ it supports, which, both as to size and mechanism, is the most powerful instrument of progression yet met with amongst extinct fishes.

Cranial Anatomy.—The skull of the extinct Sturgeon (so far as one can judge from the confused and dislocated condition of its component parts in the specimens examined) corresponds with that of the recent Sturgeon in being composed of a semi-ossified cartilaginous box, protected by a series of bony plates. Of the bones composing the maxillary arch, the palatals (Plate LXIX. 20) are most easily recognized. They are situated immediately in front of the epitympanic bones, and spread upwards, downwards, and backwards, occupying a large area, and having their broadest expanse directed forwards. They are thick and of compact structure, and having consequently resisted the effects of time more successfully than the slighter and more destructible parts, are of more frequent occurrence in the fossil specimens. The posterior process of the palatine bone is more prolonged than the corresponding part of the recent Sturgeon, and the lower anterior process to which the maxillary and premaxillary bones attach, is more expanded. The result of this character would be a more complete closure of the anterior roof of the mouth by the substitution of bone for cartilage than is the case in the existing Sturgeons. The upper anterior process is also broad for the attachment of the corresponding bone of the opposite side.

On comparing the fossil palatal bone with the recent one, the former so much resembles the latter *inverted*, that were it not for the conclusive evidence of several specimens having these bones in their proper position, the error might have been committed of describing the longer process as the anterior one, and *vice versâ*. That portion of the premaxillary bone (Plate LXIX. 22) forming the trenchant margin of the upper jaw, resembles the homologous part of the recent Sturgeon, but the long posterior process which bends backwards and downwards in the latter, turns upwards in the former. The anterior plate is triangular, and is composed of hard bony material, having a rugged outward surface occasioned by the radiation of bony fibres from a central point of ossification. It is attached to the anterior lower process of the palatine bone, and connected with its fellow on the median line. The upward direction of the long process is a material deviation from the modern type; in the latter this process overlaps the articulation of the lower jaw, whereas in the fossil genus it rather simulates a nasal process. The distal extremity, instead of being flattened as in the Sturgeon, has a rounded termination as if for articulation with the nasal cartilages, or with the corresponding process of the opposite side.

There is no satisfactory evidence in any of the specimens examined of the character of the maxillary bone. A small bifurcate bone (Plate LXIX. 21) is occasionally preserved

in a position which leads to the inference that it may be the posterior portion of this bone. It proceeds from underneath the premaxillary, and has an upward process overlapping the palatine bone, and a downward process extending in the direction of the articulation of the lower mandible*. The lower jaw (Plate LXIX. 32) is composed of a pair of single bones, narrow in front, and gradually expanding as they recede from the symphysial suture. Their upper margins are edentulous. Their outer surface is corrugated, like that of the premaxillary bones, the rugæ being longitudinal. In a depression between two of the central rugæ, a series of minute apertures are discernible, for the passage of the vessels.

The maxillary and mandibular arches are suspended, as in the recent Sturgeon, from the tympanic pedicle. Of the bones and cartilages constituting this apparatus, the epitympanic bone (Plate LXIX. 28 *a*) is the part most easily identified, and most constantly preserved. It is seen sloping backwards and downwards from a point corresponding with the mastoid process of bony fishes. The articulating process and the upper third of the shaft are rounded; the lower extremity is expanded into a thin and broad plate. Compared with the epitympanic bone of a recent Sturgeon, it differs in being longer and thinner. The upper extremity is smaller and the lower broader, and more triangular in outline, and the entire bone constitutes a far larger portion of the arch. The succeeding elements, namely, the mesotympanic and hypotympanic, which are represented in the Sturgeon by two cartilages, are united to form one bony plate (Plate LXIX. 28 *d*), somewhat crescentic in form and having a tuberosity on the interior face, at a point corresponding with the junction of the two parts, for the attachment of the hyoidean arch. This compound bone is small and feeble compared with the great strength and expanse of the epitympanic. The upper extremity which meets the anterior angle of the spatulate termination of the epitympanic is thin and pointed, and ill-adapted, either in form or dimensions, for affording an articulation of sufficient strength for the support of the mandibular and maxillary organs. It probably represents merely the thick anterior column of cartilage, which in the recent Sturgeon is of great strength and solidity; the remainder of the attachment being completed by a plate of cartilage. The hypotympanic portion of the bone is also thin, but rather stronger than the upper half. It meets the condyloid extremity of the lower jaw at an open angle. This joint, as well as the connexion with the palatine bone, was probably completed by cartilages, as in the recent type.

The dislocated condition of the specimens renders it difficult to determine the constituent parts of the hyoid arch. In two instances, a single, broad umbonated bone (Plate LXVIII. fig. 2, 42) is seen behind and below the symphysis of the lower jaw, which must be considered either as composed of the two basihyals united to form a keystone of the arch, or as the homologue of the great glossohyal or lingual bone found in the recent genera *Arapaima*, *Elops* and *Amia*, and in the extinct genus *Lophiostomus*. A bone (Plate LXVIII. fig. 2, 40), which probably represents one of the

* It is not improbable that this may prove to be the premaxillary, and that described as the premaxillary, the maxillary bone.

ceratohyals, occurs in several specimens in a position which leads to that conclusion. It has flattened extremities and a constricted shaft, resembling in outline two isosceles triangles united at the apices. The corresponding bone in the Sturgeon is shorter, broader, and thicker in all its dimensions. In one specimen a series of eight or nine plates (Plate LXIX. $_{44}$) is preserved, indicating the existence of the appendages of the hyoid arch, which are wanting in the recent Sturgeon. These homologues of the branchiostegous rays of bony fishes are flat, elongated bony laminæ, of which the upper one is the longest. They are seen in their natural position, behind the hyoid bones and immediately below the opercular flap. They have the ganoid character of the corresponding parts in the fossil genus *Pachycormus*, but are fewer in number than in that and the allied genera. The only portions of the branchial arches I have been able to determine are the epibranchials (Plate LXVIII. fig. 2, $_{48}$ *a*, *b*, *c*, *d*). These are four in number. The first or anterior bone is the longest. The upper extremity is broad and thin, the shaft and lower extremity slender and cylindrical. The two succeeding bones are less expanded above and are rather shorter. The last of the series differs from the others in having its broader extremity directed downwards. It is in fact very similar in form to the ceratohyal bone, but differs in having the upper extremity and the shaft rather more cylindrical. The number corresponds with that of the homologous parts of bony fishes, if we limit the term branchial arch to the gill supporting bones, to the exclusion of the pharyngeal arch. The proportions of the epihyals in the fossil correspond with those of the same parts in most of the bony fishes, the first being the longest, and the fourth the shortest, with a broad inferior articulation.

The sphenoid bone (Plate LXVIII. fig. 1, $_{9}$), constituting the base or platform of the cranial cavity, is more completely ossified in the extinct than in the recent Sturgeon; hence its preservation in the fossil state. The anterior or presphenoid portion of the bone (Plate LXVIII. fig. 1, $_{9}$) is extended forwards beyond the palatal bones, and the basisphenoid (Plate LXVIII. fig. 1, $_{8}$) projected backwards to the point of junction of the trunk with the head. The posterior termination of the bone was deeply notched, and so thin, that the non-existence of a distinct basioccipital bone is made evident from the absence of any articulating surface for its attachment. The alisphenoid processes (Plate LXVIII. fig. 1, $_{9}$) are given off at a point considerably in advance of the position they occupy in the generality of bony fishes; they correspond very nearly in this respect with the homologous parts of the Sturgeon. They are situate, in the fossil, 3½ inches from the posterior, and 2 inches from the anterior extremities of the bone. This extension of the bone backwards in both the recent and fossil Sturgeon, so remarkable in comparison with the relative dimensions of the elements of the sphenoid bone in the *Teleostei*, is considered by Dr. Rudolph Wagner to be effected by the calcification of the fibrous sheath of the basioccipital and postsphenoidal regions of the chorda dorsalis; Professor Owen, however, considers that its extension upon the neck, the absence of the articular concavity, and the persistence of the cartilaginous basis of the skull, are opposed to this view of its homological relations.

It has already been stated, in the description of the organs of locomotion, that in the

caudal region the processes both above and below the vertebral column were bony and persistent. In the anterior parts of the trunk, the former, or neurapophyses, are present, but the hæmapophyses are in no case preserved; the latter, together with the vertebral centra, were composed of perishable material unable to resist the process of decomposition, which the harder parts successfully withstood. Professor OWEN describes the neural arch of the vertebra in the Sturgeon as composed of "two superimposed pieces on each side, the basal portion bounding the neural canal, the apical portion the parallel canal filled by fibrous elastic ligament and adipose tissue; above this is the single cartilaginous neural spine*." The corresponding parts in the fossil connected with the anterior portion of the column are preserved in one specimen. The neurapophyses (Plate LXIX. *n a*) are expanded at each extremity, and slightly constricted in the middle region. They appear to be composed of two elements, corresponding to the basal and apical cartilages in the Sturgeon; but whether the latter embraced a second canal parallel to and above the spinal chord, I am unable to determine. Probably the substitution of bone for cartilage in the extinct genus may have rendered the support of the fibro-cartilaginous substance contained in this canal superfluous. The neural spines (Plate LXIX. *n s*) are higher than those of the Sturgeon. The highest, although not perfect, measures three-quarters of an inch. These, together with the apophyses which support them, slope backwards at a considerable inclination; but by a curve forwards at a little distance from the articulation, the former show a tendency to assume a perpendicular position. The breadth and proximity of the neural arches must have given great support and protection to the weaker parts of the spinal column.

Dermal Bones.—The roof of the cranial cavity of the extinct Sturgeon was composed, as in the recent fish, of indurated plates united to each other by close sutures. Before entering upon the description of these several parts, it is advisable to premise a few observations on the corresponding parts of the existing Sturgeon. Many attempts have been made by comparative anatomists to recognize in these cranial plates the homologues of the true epicranial bones of the bony fishes, but no conclusions have been as yet received as satisfactory. The discrepancy and irregularity observable in the size, form, and number of the head-plates, not only in the different species, but even in individuals of the same species, have been considered good and sufficient grounds for demurring to the several theories advanced as to their special and general homologies. Having had occasion to examine a considerable number of recent crania while investigating the affinities of the fossil Sturgeon, I have observed a great want of uniformity between the outer and inner demarcations of the principal cranial plates, and that, although the former may vary in number and relative proportions, the latter are constant and symmetrical. This nonconformity is frequently so marked, that a bone, single and well-defined on the inner table of the skull, may be invested with two or more scutes on the dermal surface. The suprascapular bone, for instance, usually carries two scales externally, in consequence of which deception the upper one has been con-

* Hunterian Lectures, 8vo, 1846, vol. ii. p. 53.

sidered the representative of the parietal bone, a misnomer which must of necessity invalidate the implied relations of all the surrounding parts. The knowledge of the true demarcation of this bone leads to the exposure of another error which has embarrassed the solution of this question, namely, the idea that the large posterior median plate represents the supraoccipital bone, whereas it must be considered as belonging to the series of dorsal plates, and may be designated as the nuchal scale. In front of this a smaller median plate is situated, which may with more probability be referred to the supraoccipital region. This is flanked on either side by a small lateral plate in the position of the paroccipitals, to which and the exoccipital the upper extremities of the suprascapular bones are articulated. Beneath and behind the paroccipital two plates are attached, having broad alæ descending into the cranial cavity. These may be considered the exoccipitals, or lateral elements of the neural arch of the first occipital vertebra. The upper extremity of the suprascapular and the exoccipital bone are covered externally by a single scale, concealing the junction between the two. The arch of the second cranial segment is composed of two pairs of large elongated plates. The outer pair are characterized by well-developed processes, extending downwards and inwards to meet the corresponding extremities of the alisphenoids, a character which affords strong reasons for considering them the true homologues of the mastoid bones. They extend backwards as far as the par- and ex-occipitals, and are united in front with the frontals and postfrontals. The centre pair of plates are the parietals. They articulate with the paroccipitals and the supraoccipital. The latter sends out a long median process between the parietals, in advance of which a small midfrontal plate occurs, occupying the position of the fontinelle, observable in the young Sturgeon, and sometimes present in the bony fishes, both recent and fossil. The parietals are connected laterally with the mastoids, and anteriorly with the inner posterior margins of the frontals. The third segment of the cranium is likewise composed of two pairs of plates, representing the frontals and postfrontals. The former are wedged posteriorly into the angles between the extremities of the mastoid and parietal plates, and extend forwards beyond the nasal aperture; they are flanked by the outer pair of bones, the postfrontals. These are united behind to the mastoids by strong squamose overlaps, from which points the tympano-mandibular arch is suspended.

The truth or fallacy of the homologies I have attempted to trace in the indurated portions of the cranial cartilages, must depend upon more extended investigations of the softer tissues entering into the cranial œconomy, both in the embryonic and adult conditions; in the meantime, by adopting (if only provisionally) the analogies now proposed, one object I have in view will be obtained, namely, the use of intelligible terms for comparison between the recent and fossil Sturgeons. The description given by Professor Owen, in his 'Lectures on Comparative Anatomy,' of the cartilaginous elements of the cranial bones of the Sturgeon, tends to verify the positions I have assigned to the indurated parts in the epicranial table; the difficulties which have hitherto embarrassed the subject I have attempted to overcome, by showing that these parts are composed of an

outer and an inner layer, and that although the former may, through the irregularity of its configurations, lead to erroneous suppositions as to the coincidence of its several compartments with the true cranial bones, the latter is sufficiently constant to lead to reasonable conclusions as to the homologies of its associated members.

The only portions of the cranial covering of the fossil Sturgeon as yet discovered are the parietals, the mastoids, the frontals, and the prefrontals. A small plate observable in one specimen may perhaps represent the paroccipital. None of the single median plates are indicated in any of the specimens. As a general character, all the head-bones are relatively much shorter and broader than those of the recent Sturgeon. This feature is in harmony with the short and bulky form of the trunk. The parietal plates (Plate LXIX. 7) are oblong, measuring about an inch and a half in length by three-quarters of an inch in breadth. They articulate with each other on the median line, without the intervention of the prolonged process of a supraoccipital plate. Each has a slight central umbo, from whence the fibres radiate outwards to the periphery. The mastoid plates (Plate LXIX. 8) are of larger dimensions, measuring an inch and three-quarters in length by an inch and eight-tenths in breadth. In disjointed specimens they are easily distinguished from the parietals by the position of the umbo from which the bony fibres radiate, this being situated on the outer margin of the plate. They articulate by their inner margins with the parietals. The frontals (Plates LXVIII. fig. 1, and LXIX. 11) are remarkable, in comparison with their recent homologues, for great width and contraction of the antero-posterior diameter. They measure an inch and a half in length by one inch in breadth. The corresponding dimensions of these plates in the recent specimen, from which former comparative measures have been taken, are two inches by six-tenths of an inch. The frontals articulate posteriorly with the parietals and mastoids, and, on the median line, with each other, without the interposition of a midfrontal plate or fontinelle. The centre of each plate is slightly elevated. A portion of a postfrontal plate (Plate LXIX. 19) is visible in one specimen, articulating with the frontal and mastoid. All these plates are united and interlocked by means of coarse sutures, and not by squamose overlaps, as in the recent Sturgeon. On the outer surface they are for the most part smooth, and seem to have been covered by a soft integument. A few superficial granules are scattered irregularly over some of the specimens (which may perhaps be a specific character), but there is no evidence of the deep pits and coarse radiating ornament so characteristic of the dermal scales of the Sturgeon. The same absence of surface ornament obtains with reference to the opercular apparatus. The operculum (Plates LXVII. and LXIX. 35) is a broad and flat plate, almost circular, and exceedingly thin. It has no articulating facet on the upper margin, and was probably suspended in the tegumentary tissues, deriving a certain amount of additional support from the broad posterior limb of the epitympanic bone. The outer surface is smooth and very compact. The inner surface is characterized by the occurrence of numerous minute punctures passing obliquely into the substance of the plate. The posterior outline is semicircular, adapting itself to the anterior curve of the thoracic cincture. The lower

edge is straight, and gives attachment to a small subopercular plate (Plates LXVII. and LXIX. 36), having a still smaller interoperculum (Plates LXVII. and LXIX. 37) fitted to its anterior margin. These are succeeded below by the branchiostegous rays described in a former part of this memoir. This arrangement of the opercular apparatus corresponds with that of some of the extinct fossil fishes. The preoperculum is wanting. The external characters of the cranial envelope tend to the conclusion that the dermal crust was very feebly developed in this region, and lead to the further inference that a proportionate deficiency would be found in other parts of the tegumentary covering. This was probably the case, for with the exception of the scales investing the caudal fin, no trace has been discovered of the dermal plates, so characteristic of the recent Sturgeon. The negative evidence of the non-existence of this peculiar feature is strengthened by the fact, that of all the component tissues these dermal plates are the most indestructible, and would therefore have resisted decomposition more effectually than other more tender parts, which are nevertheless found in the fossil state. The broad nuchal scale, for instance, so prominent in the recent Sturgeon, would have left some trace of its existence in specimens, where not only the surrounding bones, but even the semicartilaginous remains of the subjacent vertebral neural arches, are distinctly preserved.

Another feature bearing upon this question is seen in the natatory organs. In the recent Sturgeon, the dorsal, anal, and caudal fins are each provided with a short anterior spine springing from a dermal plate, whereas in the fossil species no such spine-bearing scales occur, the first fin-rays being supported by interapophysial osselets, as in other bony fishes. In one specimen examined by me, a portion of the skin is preserved. Viewed under the microscope, all structure characteristic of dermal tissue is obliterated, and the substance resembles a thin layer of carbonaceous material, perfectly homogeneous, and showing no trace of the bony spiculæ, which to a greater or less extent beset the smooth portions of the skin in the recent Sturgeon. I am therefore inclined to think that the fossil Sturgeon was smooth and scaleless, like the Spatulariæ of the North American rivers, although in other details of organization it had greater affinity to the more typical Sturgeons. Of these, the *Scaphyrhynchi* have the head-bones almost as smooth as those of the *Polyodon*, but the development of the dermal scales on the trunk is excessive, the caudal region being wholly encased with defensive armour. In some species we see the dermal layer thick and rugged on the head, and yet feebly developed in the trunk; while in others the deposition of bony material is coextensive on both the head and body. With regard to form, some are long and slender, others are more massive; some have elongated snouts, others have the rostrum more abrupt.

Of all the species I have examined, *Acipenser Guldenstädti* has the nearest resemblance to the fossil genus. The short snout, the proportions of the cranial plates, and the depth of the anterior part of the body, are to a certain extent approaches to the condition of these parts in the extinct form, and they are combined with the minimum amount of calcification of the integument; at the same time these are features of minor

importance to the more remarkable and distinctive characters which stamp the generic discrepancy of *Chondrosteus* from all existing forms of fish*.

Specific characters.

The collection of Fossil Fishes in the British Museum contains two specimens of *Chondrosteus*, showing some of the head-bones and a pectoral fin of individuals of gigantic proportions. Mr. HARRISON, of Charmouth, has kindly forwarded for inspection a tail of proportionate size, and which is supposed to have belonged to the same individual as one of the Museum specimens. Although size alone is no criterion of specific difference, it is nevertheless of some importance in this instance, where out of a very large number of specimens found in one locality, some are so greatly disproportioned as to be easily eliminated, while none afford any evidence of gradation from large to small. It is not, however, necessary to rely upon size alone in this case, since it is associated with other peculiarities constituting specific characters. The only portions of the head recognizable in the specimen in the British Museum are the parietal and mastoid bones. The surface of these is rough and granular, showing a considerable amount of dermal consolidation. The outer posterior angles of the mastoid bones are extended backwards, and afford articular surfaces for the attachment of the upper extremities of the suprascapulars. One of the latter bones is preserved, and measures 6 inches in length. The tail, from the collection of Mr. HARRISON, measures 18 inches in length. The lower lobe is imperfect, but the total expanse of the organ cannot have been less than 20 inches. The length of the entire fish must probably have been above 5 feet. The most remarkable character of the caudal fin is the excessive development of the scales bordering the upper margin. The size and solidity of these scales is such that they more resemble the broad teeth of an *Acrodus* than any dermal development with which I am acquainted. In consequence of this peculiarity, I have named this species *Chondrosteus pachyurus*. The numerous specimens derived from smaller individuals present indications of two species, one having the bones of the head thin and smooth, the other being characterized by stronger cranial plates, having a granulated exterior. The anal fins of the latter are more massive, and have the transverse articulations at shorter intervals (Plate LXX. A). I propose to retain the Agassizian name *Chondrosteus acipenseroides* for the former, and to designate the latter as *Chondrosteus crassior*.

General remarks.—The Sturgeons were considered by CUVIER, in his classification of fishes, to belong to the great subdivision designated, in consequence of the cartilaginous condition of the endoskeleton, *Pisces cartilaginei*; Professor AGASSIZ, however, in his great and successful effort to incorporate in one general system both the recent and extinct fishes, included them in his newly constituted family termed *Ganoidei*, from the peculiar characters of the exoskeleton. The propriety of the latter classification has been fully substantiated by Professor JOHN MÜLLER, who, after a most careful

* The gigantic fossil fish of the Whitby Lias, named by AGASSIZ *Gyrosteus mirabilis*, belongs to the Sturionidæ, and is nearly allied to *Chondrosteus*.

and elaborate examination and comparison of those recent fishes most calculated to throw light upon the subject, has concluded—1st, that the Ganoidei form a well-defined order between the true osseous fishes and the Selaceans; and 2ndly, that AGASSIZ's view of the position of the Sturgeons amongst the Ganoidei is correct. Professor OWEN considers the Sturgeon to be "one of the transitional steps from the cartilaginous to the osseous fishes," and adds the weight of his testimony to the soundness of Professor AGASSIZ's views in arranging the Sturionidæ under the ganoid order of fishes. The conclusions arrived at by these distinguished authorities resulted from the examination and comparison of the recent Sturgeons and the recent and extinct Ganoids; no evidence having been then obtained of the occurrence of the former family in the fossil state. The discovery, therefore, of a representative of the Sturionidæ in the earliest oolitic deposits, a period in which the typical ganoid fishes attained their maximum of numerical development, has a material bearing upon this subject, inasmuch as it supplies the only term of comparison wanting in the inquiry. The opportunities which I have had of examining all the specimens hitherto brought to light, have enabled me to ascertain most of the significant features of the liasic Sturgeon, the descriptions of which I have embodied in the foregoing memoir. The results may be briefly summed up as follows:—

1st. That in all essential particulars, more especially in the arrangement of the cranial plates and the oral apparatus, in the persistence of the chorda dorsalis and partial ossification of its peripheral elements, the fossil Sturgeon closely resembled the recent form.

2nd. That in the structure of the opercular and hyoid regions, and in the greater extent to which the ossification of the endoskeleton had proceeded, it approached the condition of these organs in the ganoid fishes, and constituted a transitional form between these and the recent Sturgeon.

3rd. That its bulky form and smooth integuments, contrasting so strongly with the tapering body and dermal armour of the Sturgeon, afford a striking instance of the universal law of special modification of organization for peculiar conditions of animal existence.

The Sturgeons of our own time, inhabiting the bottoms of the estuaries of mighty rivers, subject to frequent paroxysmal inundations, require not only an external form of least resistance, combined with powerful propulsory organs, to withstand the torrents to which they must necessarily be exposed in procuring their daily subsistence, but also a defensive armour sufficient to fortify their bodies against injury from stones and other detrital matters hurried down by the force of the streams. The liasic Sturgeons enjoyed a more tranquil existence. The evidence of the associated molluscan and radiate forms, proves the marine character of the waters they inhabited; the thinly laminated beds of shale and limestone from which their remains are exhumed, testify to the tranquil condition of the sea in which they lived; their smooth skin, harmonizing in tint with the muddy bottom on which they reclined, served to conceal them from the predatory Saurians and larger fishes with which they coexisted; they required neither defensive armour nor locomotive energy for self-preservation in the fulfilment of those special

functions assigned to them in this ancient ocean, although probably of the same nature as those performed now by the surviving representatives of the family.

Explanation of the Plates.

PLATE LXVII.

Chondrosteus acipenseroides, Agassiz:—reduced one-fourth.

PLATE LXVIII.

Fig. 1. Head and pectoral fins of *Chondrosteus crassior*, Egerton:—reduced one-third.
Fig. 2. Outline of the head of Plate LXVII.

PLATE LXIX.

Anterior portion of *Chondrosteus acipenseroides*, Agassiz:—reduced one-fourth.

PLATE LXX.

Anal and caudal fin of *Chondrosteus crassior*, Egerton:—natural size.

FRA INSTI LIBRA

Notation of Parts.

P. Pectoral fins.
D. Dorsal fin.
C. Caudal fin.
V. Ventral fins.
A. Anal fin.

5. Basisphenoid.
6. Alisphenoid.
7. Parietal.
8. Mastoid.
9. Presphenoid.
11. Frontal.
12. Postfrontal.
20. Palatine.
21. Maxillary.
22. Premaxillary.
28 *a*. Epitympanic.
28 *d*. Hypotympanic.
32. Dentary.
35. Opercular.
36. Subopercular.
37. Interopercular.
40. Ceratohyal.
42. Glossohyal.
44. Branchiostegal.
50. Suprascapular.
51, 52. Scapulocoracoid.
57. Metacarpal.
69. Metatarsal.
n. a. Neurapophysis.
n. s. Neural spine.
i. n. Interneural spine.
i. h. Interhæmal spine.

XXXVI. *On the Influence of Temperature on the Refraction of Light.*

By the Rev. T. P. Dale, *M.A., F.R.A.S., and Dr.* J. H. Gladstone, *F.R.S.*

Received June 17,—Read June 17, 1858.

Fraunhofer, in his original measurements of the fixed lines of the spectrum, noted the thermometer, and those who since his time have occupied themselves with the determination of refractive indices, must have frequently noticed that changes of temperature affect the amount of refraction; yet of the many observations now on record, few have affixed to them the temperature at which they were made. Baden Powell has drawn out some refractive indices of the same substance taken at different temperatures, but remarks that the whole subject, both as to the facts of the case and as to their bearing on the theoretical formulæ, remains to be investigated *. Among his beautiful researches on light, M. Jamin has recently published one or two experiments on refraction, heat, and density †; but, with this exception, he has left untouched the great question of the influence of temperature.

Some years ago Baden Powell kindly lent his instrument to one of us for the purpose of investigating this question. It is described and figured in the Report of the British Association for 1839. It consists essentially of a small telescope moving on a circle graduated so finely, that by means of a vernier and magnifying glass it may be read to 10″; to ensure accuracy, there is a vernier at each end of the moveable arm: in front of the telescope are appliances for fixing any solid prism, or a hollow prism capable of containing liquids, in such a position that there may be seen through it a ray of light proceeding from a distant slit. The telescope may be moved till a fine wire fastened in the field of view is brought to coincide with any of Fraunhofer's lines in the prismatic spectrum thus obtained, and the angle indicated by the position of the telescope on the graduated circle may be read off. In our recent joint research, as we desired to measure the positions of the extreme lines A and H, it was necessary to work with the full light of the sun; its mirrored image, therefore, was kept behind the narrow slit by means of a heliostat, and the eye was protected from the glare of the yellow rays by means of a cobalt-blue glass. Liquids were experimented on, and their temperature was changed by means either of a spirit-lamp or of a freezing mixture round the hollow prism, on a day when there was little or no moisture in the atmosphere to condense on the cold glass. A thermometer, which had been corrected by a standard instrument, was placed in the liquid contained in the hollow prism. In the experiments two practical difficulties had

* See his work on 'The Undulatory Theory as applied to the Dispersion of Light,' p. 125.

† Comptes Rendus, 29 Dec. 1856, and 23 Nov. 1857.

always to be contended with: the one was the proper fixing of the prism, so that its edge should be parallel with the slit, and that at the same time it should be kept in such a position as to indicate the minimum deviation. It was found necessary to fix this position at the commencement of the experiment, and to retain the same through all variations of temperature, though the angle of minimum deviation must vary slightly with the change of refraction; not, however, in the vast majority of cases, to an appreciable extent. A more serious difficulty was that of determining the precise temperature at which an observation was made, especially when the temperature of the liquid was much lower or higher than that of the surrounding air or brass-work; but it was to a great extent overcome by stirring the liquid in the prism with the immersed thermometer-bulb just before taking a measurement; and this had the additional advantage of bringing out the lines more distinctly; for where a liquid is very sensitive to heat and but little dispersive, as is the case with ether, the spectrum becomes too misty to see the lines unless the liquid be uniform in its temperature. A plan adopted in order to obtain observations on two or more lines at precisely the same temperature, was to bring the wire of the telescope exactly over one line, read the angle, and while it still coincided, or when next it did so, move it suddenly till it came over the other line.

The substances more or less fully examined have been bisulphide of carbon; water; ether; methylic, vinic, amylic and caprylic alcohols; hydrate of phenyl, and hydrate of cresyl, the two principal constituents of creasote; phosphorus; oil of cassia; and camphor dissolved in alcohol.

Bisulphide of Carbon.—The following Table gives the mean results of many observations made on pure colourless bisulphide of carbon, boiling at 43° C.

Temperature.	Refractive index of A.	Refractive index of D.	Refractive index of H.	Difference per 5° (D).	Length of spectrum.	Dispersive power.
0° C.	1·6217	1·6442	1·7175	0·0045	0·0958	0·1487
5	1·6180	1·6397	1·7119	0·0051	0·0939	0·1469
10	1·6144	1·6346	1·7081	0·0043	0·0937	0·1477
15	1·6114	1·6303	1·7035	0·0042	0·0921	0·1462
20	1·6076	1·6261	1·6993	0·0041	0·0917	0·1463
25	1·6036	1·6220	1·6942	0·0038	0·0906	0·1460
30	1·5995	1·6182	1·6896	0·0042	0·0901	0·1457
35	1·5956	1·6140	1·6850	0·0037	0·0894	0·1456
40	1·5919	1·6103	1·6810	0·0042	0·0891	0·1459
42·5	1·5900	1·6082	1·6778		0·0878	0·1443

The three columns that give the refractive indices of the fixed lines of the spectrum A, D, and H respectively, speak for themselves.

The next column represents the amount of change of refractive index which the substance exhibits, for each 5° of temperature. For this change the term *sensitiveness* is proposed. The difference is evidently uniform, or nearly so, the irregularities being within the limits of errors of observation. It is reckoned from the indices of the line D, as that line very nearly represents the point of mean refraction in the spectrum, and a glance will suffice to show that were it reckoned for either A or H, the average would

be somewhat different, the whole amount of difference of refraction between 0° C. and 42°·5 C. being for A, 0·0317, for D, 0·0360, and for H, 0·0397. This fact is exhibited, though under another form, in the succeeding column, where the refractive index for A is subtracted from that for H; and as these lines are at the two extremities of the prismatic image, $\mu_H - \mu_A$ represents the measureable length of the spectrum. It evidently decreases as the temperature rises.

The last column gives the dispersive power at the different temperatures, that is, the ratio between the length of the spectrum and the mean refraction, or $\frac{\mu_H - \mu_A}{\mu_D - 1}$.

The refractive indices of all the larger lines at 15° C. have been thus determined:—

A.	B.	C.	D.	E.	F.	G.	H.
1·6114	1·6177	1·6209	1·6303	1·6434	1·6554	1·6799	1·7035

Water.—Distilled water, which had been boiled to expel the air, was examined, as also Wenham Lake ice-water. The following Table gives the average of several determinations:—

Temperature.	Refractive index of A.	Refractive index of D.	Refractive index of H.	Sensitiveness per 5° (D).	Length of spectrum.	Dispersive power.
0° C.	1·3291	1·3330	1·3438		0·0147	0·0429
				0·0001		
5	1·3290	1·3329	1·3436		0·0146	
				0·0002		
10	1·3288	1·3327	1·3434		0·0146	0·0439
				0·0003		
15	1·3284	1·3324	1·3431		0·0147	
				0·0004		
20	1·3279	1·3320	1·3427		0·0148	0·0445
				0·0003		
25	1·3275	1·3317	1·3420		0·0145	
				0·0006		
30	1·3270	1·3309	1·3415		0·0145	0·0438
				0·0006		
35	1·3264	1·3303	1·3410		0·0146	
				0·0006		
40	1·3257	1·3297	1·3405		0·0148	0·0449
				0·0009		
45	1·3250	1·3288	1·3396		0·0146	
				0·0008		
50	1·3241	1·3280	1·3388		0·0147	0·0448
				0·0009		
55	1·3235	1·3271	1·3380		0·0145	
				0·0012		
60	1·3223	1·3259	1·3367		0·0144	0·0441
				0·0010		
65	1·3218	1·3249	.....			
				0·0012		
70	1·3203	1·3237	1·3344		0·0141	0·0435
				0·0012(A)		
80	1·3178	.....	1·3321		0·0143	

The experiments of JAMIN were also made with water. He was desirous of determining whether the index of refraction varied *pari passu* with the density, which it should do if the theory of emission be the correct one; accordingly he gradually cooled down water to the freezing-point, and found that the index steadily increased, passed 4° C., the point of maximum density, and still increased till 0°. Hence he deduced the independence of the two phenomena, change of density, and change of refraction by heat. His instrument, being constructed so as to take advantage of the phenomena of interference, is more delicate than that employed by us, but it is more difficult to obtain numerical data by it. Our determinations were performed repeatedly and most carefully on water near the freezing-point: they confirm the observations of the French physicist, but show at the same time that the remarkable reversion of the change of

density at 4° C. is not without its influence on the amount of sensitiveness; the change of refractive index between 10° and 5° being 0·0002, while that between 5° and 0° is only 0·0001. This fact, however, will come out more plainly on a reference to the following Table, which represents the refractive indices of one of the series of observations made with especial view to this point. The indices are calculated to five places of decimals.

Temperature.	Refractive index of A.	Refractive index of D.	Refractive index of H.
0° C.	.....	1·33374	.....
1	1·32913	.....	1·34377
2	1·32913	.....	1·34377
3	1·32913	.....	.....
4	1·32902	1·33367	1·34366
6·5	.....	1·33356	1·34366
9	1·32882	1·33342	1·34337
11	1·32879	.....	1·34331

Nor is this the only indication of the influence of change in density exhibited by the Table of indices of water. It is there evident that the sensitiveness of water is greater at high than at low temperatures; so is its change of density; but the two do not proceed *pari passu*. It is well known also that water becomes much lighter specifically as it freezes; it has also been observed that the refractive index of ice is much less than that of water. The following determinations will show that the two changes are almost identical in amount, or rather that the ratio between the density and the mean refraction, $\mu_D - 1$, is almost constant. The refractive index of ice was determined for D at 1·3089 and

Substance.	Mean refraction.	Specific gravity.	Refractive power.
Ice at ... 0°	0·3089	0·9184*	2973
Water at 0°	0·3330	1·0000	3003

The similarity is here so close as to suggest the idea that the slight discrepancy is due to errors of experiment. If it be so, water has not changed its refractive power by passing from the liquid to the solid state, and another deduction of M. Jamin may be made more general. He found that the refraction of water under different pressures varied in precise accordance with the amount of condensation, and concluded that "it may be admitted that this law of constancy of the refractive power is worthy of acceptance when the water does not change its physical condition, and remaining at the same temperature, is submitted to variable pressure." The law may prove to be worthy of acceptance even when water does change its physical condition from the liquid to the solid.

The refractive indices of the principal fixed lines were determined as follows at a temperature of 15° C.:—

* According to Playfair and Joule, Mem. Chem. Soc. vol. ii.

A.	B.	C.	D.	E.	F.	G.	H.
1·3284	1·3300	1·3307	1·3324	1·3347	1·3366	1·3402	1·3431

These measurements agree very closely with those previously published by FRAUNHOFER and by POWELL.

Ether.—Anhydrous ether boiling at 35° C. gave the following results* :—

Temperature.	Refractive index of A.	Refractive index of D.	Refractive index of H.	Sensitiveness per 5° (D).	Length of spectrum.	Dispersive power.
5° C.	1·3585	1·3622	1·3740		0·0155	0·0428
10	1·3555	1·3592	1·3707	0·0030	0·0152	0·0423
15	1·3529	1·3566	1·3683	0·0026	0·0154	0·0431
20	1·3508	1·3545	1·3658	0·0021	0·0150	0·0423
25	1·3485	1·3519	1·3635	0·0026	0·0150	0·0426
30	1·3460	1·3496	1·3611	0·0023	0·0151	0·0432
34	1·3442	1·3477	1·3595	0·0024	0·0153	0·0440

The following measurements of the principal fixed lines were obtained at 15° C. :—

A.	B.	C.	D.	E.	F.	G.	H.
1·3529	1·3545	1·3554	1·3566	1·3590	1·3606	1·3646	1·3683

Alcohol.—The following Table represents the mean results of many experiments performed with absolute alcohol. In order to prevent the alcohol absorbing water from the surrounding atmosphere during the course of the experiments, they were performed on frosty days when the air contained no moisture.

Temperature.	Refractive index of A.	Refractive index of D.	Refractive index of H.	Sensitiveness per 5° (A).	Length of spectrum.	Dispersive power.
0° C.	1·3658	.....	1·3811		0·0153	
5	1·3639	.....	1·3793	0·0019	0·0154	
10	1·3617	1·3658	1·3769	0·0022	0·0152	0·0415
15	1·3600	1·3638	1·3751	0·0017	0·0151	0·0415
20	1·3578	1·3615	1·3730	0·0022	0·0152	0·0419
25	1·3554	1·3598	1·3706	0·0024	0·0152	0·0419
30	1·3537	1·3578	1·3687	0·0017	0·0150	0·0418
35	1·3513	1·3556	1·3661	0·0024	0·0148	0·0416
40	1·3495	1·3536	1·3643	0·0018	0·0148	0·0417
45	1·3475	1·3514	1·3624	0·0020	0·0149	0·0424
50	1·3451	1·3491	1·3599	0·0024	0·0148	0·0423
60	1·3407	1·3437	1·3558	0·0022	0·0151	0·0439

The refractive indices were thus determined for all the principal fixed lines at 15° C.

A.	B.	C.	D.	E.	F.	G.	H.
1·3600	1·3612	1·3621	1·3638	1·3661	1·3683	1·3720	1·3751

Wood Spirit.—The purest specimen of methylic alcohol which we could obtain, but which, when rendered anhydrous, had too low a boiling-point, was examined on a day when the dew-point was as low as 0°·6 C.

* This Table was substituted during the printing for a less accurate one.

Temperature.	Refractive index of A.	Refractive index of D.	Refractive index of H.	Sensitiveness per 5° (A).	Length of spectrum.	Dispersive power.
0° C.	1·3378	.....	1·3519	0·0017	0·0141	
5	1·3361	.....	1·3500	0·0018	0·0139	
10	1·3343	1·3379	1·3483	0·0013	0·0140	0·0414
30	1·3292	.....	1·3432	0·0022	0·0140	
40	1·3247	1·3297	1·3387	0·0030	0·0140	0·0424
50	1·3187	.....	1·3331		0·0144	

This Table, though imperfect, suffices to show the close analogy in every respect between methylic and ethylic alcohol.

Amylic Alcohol and *Caprylic Alcohol.*—These two alcohols, the specimen of the first boiling at 130° to 132° C., that of the second at about 181° C., yielded results very comparable with those of the alcohols previously examined, though they are more refractive than their congeners lower in the series. Indeed, it seems probable that an advance in refractive power occurs with each increment of $C_2 H_2$. A similar advance in the length of the spectrum is also perceptible, but not in the sensitiveness. The following Table will sufficiently exhibit this:—

Alcohol.	Temperature.	Refractive index of A.	Refractive index of H.	Sensitiveness per 10°.	Length of spectrum.
Methylic:—	0° C.	1·3378	1·3519	0·0035	0·0141
$C_2 H_4 O_2$	10	1·3343	1·3483		0·0140
Ethylic:—	0	1·3658	1·3811	0·0041	0·0153
$C_4 H_6 O_2$	10	1·3617	1·3769		0·0152
Amylic:—	0	1·4084	1·4263	0·0024	0·0179
$C_{10} H_{12} O_2$	10	1·4060	1·4238		0·0178
Caprylic:—	0	1·4291	1·4504	0·0039	0·0213
$C_{16} H_{18} O_2$	10	1·4252	1·4454		0·0202

Hydrate of Phenyl.—A specimen of this substance, the principal constituent of creasote, boiling at 187° C., was examined. It was solid at the ordinary temperature, but on cooling gradually in the prism, it remained liquid even at 12°·5 C. The addition of a little solid hydrate caused the whole then to fly into crystals with the evolution of sensible heat. As this body has also a great attraction for water, the experiment was performed on a very cold dry day.

Temperature.	Refractive index of A.	Refractive index of D.	Refractive index of H.	Sensitiveness per 5° (D).	Length of spectrum.	Dispersive power.
13° C.	1·5377	1·5488	1·5886	0·0025	0·0509	0·0927
25	1·5321	1·5429	1·5823	0·0016	0·0502	
30	1·5301	1·5413	1·5802	0·0027	0·0501	0·0925
35	1·5276	1·5386	1·5773	0·0024	0·0498	
40	1·5254	1·5362	1·5748	0·0025	0·0494	0·0921
45	1·5230	1·5337	1·5717	0·0026	0·0487	
50	1·5205	1·5311	1·5692	0·0024	0·0487	0·0916
60	1·5156	1·5262	1·5637	0·0024	0·0481	0·0914
65	1·5132	1·5238	1·5616	0·0029	0·0484	
70	1·5109	1·5209	1·5587		0·0476	0·0913

The principal fixed lines were found to have the following refractive indices at 13° C.:—

A.	B.	C.	D.	E.	F.	G.	H.
1·5377	1·5416	1·5433	1·5488	1·5564	1·5639	1·5763	1·5886

Hydrate of Cresyl.—A portion of creasote, which after repeated distillations boiled at 201° to 205° C., was submitted to examination. It consisted mainly, no doubt, of the higher homologue of hydrate of phenyl, which has been designated hydrate of cresyl, differing from it by one increment of C_2H_2; yet the liquid could scarcely be considered a pure specimen of that substance. It gave results almost identical with those obtained with hydrate of phenyl, in the amount of refraction, dispersion, and sensitiveness.

Phosphorus.—As phosphorus is one of the most refractive substances known, and an element, it was thought desirable to determine the change produced in its relation to light by change of temperature. The fixed lines of the spectrum, however, could not be recognized through melted or solid phosphorus; and when of the ordinary pale yellow colour, it absorbed the extreme red about A. By employing a red glass as an absorbent medium, the following determinations of the position of the orange-red ray about C were obtained:—

Temperature.	Refractive index of C (about)	Sensitiveness per 5° C.
30° C.	2·0741	
35	2·0709	0·0032
40	2·0677	0·0032
45	2·0640	0·0037
50	2·0603	0·0037
55	2·0557	0·0046
60	2·0515	0·0042
65	2·0473	0·0042
70	2·0422	0·0051

The extreme violet ray at 40° had, as nearly as could be determined, a refractive index of 2·2356, giving the enormous length of the spectrum 0·1679, from C to H.

Solid phosphorus, at 35° C., was found to give the index 2·1168 for the orange-red ray. On solidifying, this substance also experiences a great increase of density.

Oil of Cassia.—As this oil is reputed to be one of the most dispersive substances known, and highly refractive too, it presents points of great interest; but unfortunately it is no definite chemical compound; and the specimen examined by us, and which was said to be very pure, was far less dispersive than that employed by the Rev. Baden Powell. It had also a slight yellow tint, arising from the partial absorption of the most refrangible rays. The following determinations were made, the line G being necessarily measured instead of H:—

Temperature.	Refractive index of A.	Refractive index of D.	Refractive index of G.	Sensitiveness for 5° (A).	Length of spectrum, $\mu_G - \mu_A$.	Dispersive power.
25° C.	1·5700	1·5880	1·6414	0·0022	0·0714	0·1214
30	1·5678	.....	1·6389	0·0025	0·0711	
35	1·5653	1·5832	1·6361	0·0024	0·0708	0·1214
40	1·5629	1·5796	1·6328	0·0029	0·0699	0·1206
45	1·5600	.....	1·6296	0·0026	0·0696	
50	1·5574	.....	1·6266	0·0027	0·0692	
60	1·5520	1·5690	1·6200		0·0680	0·1195

Camphor in Alcohol.—Alcohol, saturated with camphor at about 25° C., was rendered considerably more refractive and dispersive, but its sensitiveness remained almost exactly the same.

A comparison of the observations here noted seems to warrant the following conclusions:—

I. In every substance the refractive index diminishes as the temperature increases. The comparative amount of sensitiveness varies greatly, from 0·0042 per 5° C. in phosphorus to as little as 0·0002 in water.

II. The length of the spectrum varies as the temperature increases. In the case of highly dispersive bodies, as bisulphide of carbon and hydrate of phenyl, it decreases considerably; in the case of less dispersive bodies, as the alcohols, it decreases to a less extent; while with water the decrease is scarcely appreciable.

III. In some substances the dispersive power is diminished, in others it is augmented by a rise of temperature; that is, in such substances as bisulphide of carbon, it is the numerator of the function $\frac{\mu_H - \mu_A}{\mu_D - 1}$ that decreases fastest, while in such substances as water it is the denominator.

IV. The sensitiveness of a substance is independent of its specific refractive or dispersive power. Thus water and ether are very similar as to the actual amount of the refraction and dispersion exhibited by them at the ordinary temperature, but ether is many times more sensitive to heat than water is.

V. The amount of sensitiveness is not directly proportional to the change of density produced by alteration of temperature, yet there is some relationship between the two phenomena. This has been already pointed out in reference to water; and in general those substances that are most affected in density by heat are the most sensitive.

VI. No sudden change of sensitiveness occurs near the boiling-point; at least, this is true in respect to bisulphide of carbon, ether, and methylic alcohol.

The Rev. T. P. Dale originated this inquiry. He too is responsible for the calculations, and Dr. Gladstone for all the angular measurements on which they are based, and the purity of the substances employed.

XXXVII. *On the Structure and Functions of the Hairs of the Crustacea.* By CAMPBELL DE MORGAN, *Surgeon to the Middlesex Hospital. Communicated by* GEORGE BUSK, *Esq.*

Received March 13,—Read April 29, 1858.

THE observations of M. LAVALLE* on the structure of the hairs attached to the shell of the decapodous Crustacea, have shown that these organs are not mere appendages to the shell, as was formerly supposed (see SIEBOLD†), but that they are *sometimes* connected with canals which penetrate its whole thickness, in such a manner that there seems to be a continuity of the material which fills the hair with that which exists in the corresponding canal. The hairs are traversed by a canal; at their base they expand into a bulb, which is received into a cup-shaped cavity in the outer pigmentary layer of the shell, and which is limited to that part, never being prolonged into the inner layers of the shell. This cup-shaped cavity is the termination of a canal which traverses the entire thickness of the shell, and is here expanded so as to enclose the bulb. The canal of the hair is enlarged at the situation of the bulb. It is then constricted, but it opens below into its receiving cavity, and is continuous with the canal of the shell.

M. HOLLARD‡, who has investigated the structures of the hairs in many of the articulated classes, finds that there exists in them the same general character of being hollow organs connected with canals channeled out in the hard tegumentary coverings of the body.

Of the hairs of the Crustacea, especially, he says that the canals of the shell which correspond to the hairs are occupied by membranous investments, which embrace the base of the hairs, and constitute follicular sacs, *terminating inferiorly in a conical* extremity; and that they seem to receive through it a nutrient system, of which the debris are easily recognized in most preparations.

The general conclusions at which he arrives with regard to insects, indicate, though vaguely, that these organs may be, amongst other functions, connected with general sensation§.

* Annales des Sciences Naturelles, 1847.

† Anatomy of the Invertebrata.—"The tubules, points, bristles, single and bifid hairs, which are usually hollow, and exist on the surface or borders of the different parts of the cutaneous skeleton, are always mere prolongations or simple excrescences of the integument, and contain its characteristic substance—chitine." —BENNETT's Translation, p. 310.

‡ Revue et Magasin de Zoologie, 1851.

§ "Enfin, nettement limités par leur base d'implantation, revêtant la forme d'un pédicule étroit ou d'un renflement, les poils et les écailles des *entomozoaires* sont toujours reçus dans de petits sacs: et, chez un certain nombre d'espèces, on voit facilement, que ces sacs, véritables follicules, reçoivent par leur fond ou

In some recent observations by Dr. Ernst Häckel*, attention has been directed to the tissues immediately below the shell. Milne-Edwards had already described this tissue as consisting of three layers,—an outer, thin and firm, but non-vascular; an inner, resembling the serous membrane of the higher animals, and investing especially the viscera; and a middle, soft, spongy, and very vascular layer, which he regards as a chorium or dermis. The tissue had also been fully described by C. Schmidt and others. Dr. Häckel is, however, the first who has published, so far as the author can ascertain, an account of the connexion of the internal tissue with the hairs. He considers the external layer of the tissue which lies below the shell as a chitinogenous layer, composed of epithelial cells, which he calls chitinogenous cells; and he regards the office of this layer, as implied by the name which he has given to it, to be the formation of the shell, which is, according to him, a hardened secretion of the cells, laid down in layers like a cuticle. The soft tissue which lies below the chitinogenous layer, he describes as consisting of more or less firm homogeneous connective tissue, which supports the vessels and nerves. Now it is the chitinogenous layer alone which he describes and figures as entering the large pore-canals of the shell, and continuing on to invest the hair-cavity; and he does not appear to recognize any connexion between the shell and hair-canals, and the soft vascular and nervous layer below the cuticle or chitinogenous membrane.

The object of this paper is to determine the true connexion of the hairs and bristles, and hence to indicate their probable use. Differences have been noticed in the arrangement and form of the hairs in the animals which have been examined, but the general mode of their connexion with the shell, and with the parts internal to it, is so much the same in all as not to require or even to admit of special description.

Whether the shell is to be regarded as the homologue of the epidermis of the higher animals, is not here a matter of any consequence. In its perfect and hardened state, the tissue of which it is composed is too compact and dense to justify the belief that it is vascular or sensitive. But the tissue below it, which is freely supplied with nerves, may fairly be regarded as the homologue of the chorium of the higher animals, and like it, as endowed with more or less sensibility; this must apply, however, only to the vascular, soft, connective tissue, not to the chitinogenous membrane, which is clearly epidermic. Now the following observations will, it is believed, prove that while the hairs and their corresponding shell canals are lined by the outer chitinogenous membrane, their most important connexion is with the sensitive pulp which lies below it. The best situations for showing this are some of those parts in which the shell is thin, as, for example, in the antennæ or in the foot-jaws of the larger Crustacea (Plate LXXI. fig. 1). If a section

des trachées, ou des filets nerveux peut-être, chez les espèces à système vasculaire, des canaux nourriciers. Nous voilà donc bien loin des poils épidermiques de la plante, et bien près des poils bulboïdes des mammifères et des plumes des oiseaux, y compris les modifications de forme, de structure, d'organisation qui se rapportent à la différence des séjours, et des fonctions plus ou moins relatives à la protection, à la statique, peut-être même, à la sensation générale."

* Über die Gewebe des Flusskrebses. Müller's Archiv, 1857, p. 469.

be made in such a part in the plane of the hairs, the canals leading to them will be often found to be nearly as large as the base of the hairs to which the canals correspond. They are lined by a thick, transparent, chitinous membrane, within which may be seen the outer layer of the internal integument. The chitinous lining, after investing the cup-shaped cavity which receives the hair, becomes so firmly connected with the bulb of the hair itself, that on tearing out the hair, which cannot be done without force, the sheath will often be dragged out with it.

The cells and other elements of the spongy middle layer of the internal integument fill up the canal, and pass on through the opening at the root of the hair into the hair-canals.

In every part in which the hairs have been examined, their connexion with the vascular internal membrane has been observed. But where the shell is very thick, as in the claw of the Lobster, some manipulation is necessary to its clear demonstration. If fine sections be made of a claw which has been softened in dilute nitric acid, the canals of the shell will be seen to terminate in cup-shaped cavities, which receive the hair-bulbs and are continuous with the hair-tubes. The shell canals are comparatively fine, more resembling coarse dentinal tubes; but they are lined by a sheath, and have contents prolonged from the vascular layer. If the plan be adopted by which Mr. TOMES demonstrated the presence of the dentinal fibres*, viz. tearing the section across the direction of the canals, their sheaths will be dragged out in the form of tubes, from which the contents have sometimes escaped, so that only air is contained in them, though generally their contents may be still seen in them (fig. 2 *a*). The relations of the contents of the tubes to the internal integument may be shown by tearing away the latter from the shell, when the contents will often be drawn out of the canals; and it may be seen that they are prolongations of the outer layer of the integument, enclosing the elements of the vascular layer within their tubular cavities (fig. 2 *c*).

The uniform and intimate connexion of the hairs with the living structures within the shell indicates that they are not mere appendages to it, like the tubercles, but that they have some function distinct from it, and associated rather with the deeper-seated nervous and vascular structures. The most natural conclusion appears to be, that, like the whiskers of the Seal or of the feline Carnivora, and indeed like the hairs of the Mammalia generally, they are a means of transmitting sensation from without to the sensitive parts within. It is generally assumed that the greater part of the body of crustaceans is destitute of sensibility, though the antennæ and oral appendages have been known to possess it to a great extent. It is not easy to conceive, however, that the dense calcareous coverings of these parts could be the medium of communicating any delicate impressions, such as are evidently conveyed by the antennæ. There is no difficulty in understanding this, on the supposition that the hairs which surround each joint of the antennæ, and each border of the oral appendages, are in direct relation with a sensitive pulp within, and that the impressions made upon their base would be at once communicated to this pulp.

* Philosophical Transactions, 1856.

While no doubt the hairs have other and mechanical offices to fulfil, it would be difficult to suggest any use besides that of ministering to sensation which could demand their close and direct union with the living nervous and vascular membrane.

This view derives great support from the fact of the existence of a structure within the claw of the larger crustaceans, which, so far as the author can learn, has not hitherto been described.

It is generally stated that the claw is entirely filled with the muscular apparatus belonging to it, but this is by no means the case. Neither the moveable piece or index, nor the part of the tarsus which it opposes, the pollex, contain any muscular tissue. The flexor and extensor of the index, terminate at the level of the joint of the pincer, where the tendon is inserted, and all below this level is filled with a spongy mass similar in structure to that of the internal integument. Into this mass the nerves of the limb principally pass. The muscles are supplied almost entirely by a small branch, while the principal nerve divides at about the level of the penultimate joint into two trunks, which pass down one towards each limb of the claw, and then break up into their terminal branches, which are distributed to the spongy tissue of the claw. The bristles of the claw in the Lobster are placed in regular series of short tufts along the sharp margin of the index, protected by the fine tubercles which stud this edge, and beyond which they do not project. On the broad, heavily tuberculated border of the larger claw, the bristles are often entirely absent; but the communication between this margin and the pulp within, is maintained by means of a line of numerous canals situated principally at the sides of the tubercles, never on them, which reach to the surface, and there terminate in bulbous extremities, which contain the same matter as that found in the cavities for the hairs (fig. 2 *b*). These bulbous extremities of the canals, which have much the appearance of imperfectly developed hairs, sometimes project a little beyond the level of the external surface of the shell, sometimes lie below and are lodged in depressions in it.

In the Crab's claw, where the tubercles are deficient, and the limbs of the pincers comparatively small, the tufts of bristles give place almost entirely to these hairless pulp-cavities. The structures within are the same as in the Lobster, but on a much less developed scale.

Here, then, lodged within the densest part of the shell, is a structure richly supplied with nerves, shut off from other parts of the body, and having communication with the surface only through the medium of canals, which are sometimes continued into bristles, and sometimes terminate in mere bulbs. As a prehensile organ, the claw probably needs sensibility; but no force which the animal could exercise could make any impression on the parts within, through its dense tuberculated edges. On the other hand, it is difficult to assign any office to the bristles, and still more to the bulbs, mechanical or otherwise, except that which has been here suggested,—that, establishing, as they do, a communication between the external surface and the contained nervous structure, they communicate impressions to it, and are in fact tactile organs.

If this supposition be correct, the chitinogenous layer of M. HÄCKEL could not be the only medium of communication between the hairs and the internal parts. The author had satisfied himself before the appearance of M. HÄCKEL's paper on the subject, that the inner vascular and nervous pulp sent prolongations into the hairs, and he had too, even in the Lobster, seen indications of arrangement of the pulp which conveyed to him the impression that it was formed with reference to the hairs, rather than that the hairs were mere appendages to it. He was anxious naturally to ascertain in how far this view was correct.

In the larger Crustacea, however, the pulp is for the most part too thick and opaque to admit of examination in its entire state, and too soft to admit of section without destruction to its characters. But in some of the smaller ones, as, for example, in the Shrimp, the mode of arrangement of the inner soft layers can, with a little precaution, be readily seen. In examining the tissues in these animals, a confirmation of the views already advanced in this paper will be found in the presence of an arrangement of structure so remarkable as to require special description.

The flabellum on which the eye appears to rest, is perhaps the situation in which this arrangement can be most easily demonstrated. If the shell be carefully stripped away from the contained pulp, the chitinous investment of the hairs will be removed with it, while their contents will be drawn out from their canals and will remain in connexion with the pulp. It will be seen, on examining the pulp, that it is composed of an extremely delicate chitinous lamina, which supports the fibrous and cellular structure of the chorium, and which is connected with the tubes to be presently described.

Through the centre from behind forwards, the chorium forms a more dense mass (fig. 3 *a*), in which lie the nerves and principal vessels. The outer side is continued forwards in a small cone-shaped process (*b*), which corresponds to a similar process of the shell, and may be traced for some distance towards the base of the organ. At the inner and anterior part, lies a series of tubes which radiate forwards from the denser central mass. These tubes appear to be composed of firm chitinous sheaths, covered externally by the epidermic or chitinogenous layer of HÄCKEL. At their outer ends they are somewhat contracted (fig. 4); at their inner end, towards the anterior part of the organ, they appear to merge into the general cellular mass of the chorium; but more towards its base they are truncated, and their terminations are clearly defined (fig. 3 *d*). Projecting from their outer ends are seen fibres, which correspond to, and have been drawn from, the hairs (fig. 3 *c*). These fibres can be traced through the whole length of the tubes; but towards the inner truncated end of the tubes they are usually lost in the cellular mass of the chorium, though sometimes they appear as projecting fibres when the tubes are torn away from the parts with which they were connected.

The fibres in the flabellum seem to consist of an outer pellucid tubular coat, with contents of a more opaque character (fig. 4). At their outer free ends, which project from the tubes, the fibres assume various characters, in accordance with the form of the

hairs to which they belong. Sometimes they are split into two or three branches, sometimes they present serrated margins, and at times they have a plumose character, from the presence of secondary fibres which correspond with the plumules of the hairs. Hence it is evident, that although in the examination of the hairs none of the contents can be seen entering the secondary processes, yet that in reality they do receive continuations from the internal structures of the hairs.

The tubular, fibre-containing structure may be found readily in some of the smaller maxillary appendages.

In the terminal joint of the larger maxillary foot of the Shrimp, in which the hairs form a sort of brush all around it, the tubes may be seen clustered together, their openings arranged in rows corresponding to the rows of hairs, as seen in figs. 5 and 6.

But it is not only in parts which are usually recognized as ministering to sensation that this structure is found. The same may be seen wherever the hairs are abundant, as, for example, in the ambulatory organs and in the claw. In order to show this distinctly, it is necessary, after removing the shell, to pick away the muscles from within the chorium, and then the tubes and their contained fibres will be at once seen.

In describing the connexion of the hairs with the chorium in the Lobster and larger Crustacea, and the existence of the mass of pulp largely supplied with nerves which is contained in the terminal joints of the claw, it was assumed that there was an association between the nerves and the hairs. In these larger animals, however, the author could not trace in a satisfactory manner such a connexion, though he often saw bundles and fibres, which he believed to be nerve tissue passing towards the hair-tubes.

In the claw of the Shrimp, however, the nerves can be traced so directly into the immediate neighbourhood of the hair-fibres, as to leave no room for doubt as to their relation to them. The general structure is the same as in the Lobster, but there are some peculiarities which deserve special mention. The pollex and index do not meet so as to resemble pincers, but the sharp scythe-shaped pollex (fig. 7 *a*) folds down upon the margin of the metatarsus, and merely touches with its extremity a small process which projects on the opposite side of the metatarsus (*b*), and which may be considered as an index. The extremity of the metatarsus to which the pollex is applied, presents a thin central lamina (*c*), on each side of which, and protected as it were by it, is a row of very delicate hairs. If the chorium be carefully dragged away from the shell, and the muscles drawn out from it, the hair-fibres will be found passing into a tubular structure much like that before described, while their free extremities rest on a very delicate lamina, which is probably the chitinogenous membrane of the corresponding lamina of the shell before noticed, and which invests it on both sides. Running into the deep layer of the chorium in which the hair-fibres are imbedded, is seen a large nerve branch (*d*), which spreads out when it reaches this structure. The ultimate distribution of the nerve can as yet be only surmised, but as the structure connected with the fibres is the only one in this situation, there can be no doubt that the nerve is directly associated with them.

The position of the hairs on each side of a lamina to which the pollex is opposed, is precisely analogous to that of the hairs in the claw of the Lobster, where they are placed, not upon, but to the sides of the tubercles, and are thus protected from the direct force of the opposing claws.

The author has been unwilling to multiply examples, and he conceives that enough has been brought forward to prove that the hairs of the Crustacea are in intimate relation with the deep layer of the inner integument in which the nerves terminate, and not with the epidermic or chitinogenous layer only; that the structure of this integument is in many instances arranged entirely with reference to its connexion with the hairs; that the hairs cannot therefore be regarded as prolongations of the shell, but as prolongations of the chorium protected by a special chitinous investment; and finally, that although many other offices are performed by them, yet that their relation to the chorium justifies the conclusion that they correspond to the papillæ of the skin in the higher animals, and that they are organs of general or special sensibility.

Appendix.

Since this paper was communicated to the Society, the author has found in parts of the Prawn a more direct confirmation of his views as to the connexion of the nerves with the hairs than he had previously seen.

In the flabella of the tail of the smaller Prawns the shell is so thin, and so nearly homogeneous in structure, that the soft textures within can be seen perfectly through it. The chorium presents an appearance of tubular structure radiating towards the hairs, like that which has been described in the Shrimp; but the tubules are far less clearly defined (fig. 8), and do not appear to possess a chitinous basis. Bands or fibres can be seen passing from the extremities of the tubules into the hairs. These fibres, however, which are very delicate and contain no chitine, cannot be traced, as is the case in the Shrimp, far into the tubular structure. They appear rather to lose themselves towards the outer margin of the tubular chorium, which, instead of presenting distinct orifices, has a granular or cellular-looking boundary. The nerve (fig. 7 *d*) can be seen entering the flabellum at its base as a large cord, which soon subdivides and ultimately breaks up into fibres, which can be traced into the tubules, and appear to be continued on to the margin of the chorium. Some of these filaments seem to terminate in the cellular boundary, while others pass on to the bands or fibres which go to the hairs.

Although the sheaths and fibres of chitine which have been described in the Shrimp are not found in the Prawn, yet in the flabelliform processes of some of the larger prawns the author has found elongated and extremely delicate chitinous fibres, extending from the inner part of the tubular layer towards the roots of the hairs. They do not appear to be so directly connected with the hairs as those which exist in the Shrimp, and may perhaps serve the purpose of the delicate chitinous lamina which in the Shrimp gives support to the chorium and to the tubular structure.

The flabelliform appendages to the head and the posterior abdominal appendages show something of the same characters, but in a less marked degree.

The extreme delicacy and softness of the chorium in the Prawn has prevented the author from extracting it in such a state as to be fitted for examination from those parts where the shell is thick, as the claws and ambulatory feet.

The view which is here taken of the uses of the hairs, and which seems to be proved by their anatomical relations, is one which has been considered by many as probable, though, so far as is known to the author, no investigations have been made which bear directly upon it, except those of Dr. ARTHUR FARRE on the organ of hearing in the Crustacea*.

The author regrets that he had not Dr. FARRE'S interesting paper before him when the present communication was first sent in to the Society, as it gives a beautiful illustration of the fact of the hairs being made the instruments for the conveyance of delicate impressions. He describes the hairs of the auditory apparatus as hollow, with numerous granules—apparently nerve-granules—contained in them, while the auditory nerve may be traced in the form of a plexus at their very base; and he considers that the hairs or ciliated processes immediately overlying this plexus, exhibit an apparatus for extending the extremities of the nerves in such a manner as to render them sensitive to the most delicate vibration of the fluid with which the sac of the hearing organ is filled. He is thus led to regard the hairs of the inner sac of the ear as representing a delicate series of antennæ.

The observations brought under the notice of the Society in the present communication, tend to prove the correctness of Dr. FARRE'S views on the uses of the hairs found in the organ of hearing, as well as of the general conclusion at which he hints, that the apparatus found in that organ will present, on a most refined scale, a repetition of the form of an organ of touch.

EXPLANATION OF THE PLATE.

PLATE LXXI.

Fig. 1. Section of part of a foot-jaw of the Lobster; showing the roots of three hairs (*a*), with their shell canals (*b*), and the connexion of their contents with the vascular layer (*c*) of the internal integument.

Fig. 2. From the larger claw of the Lobster: the section is torn, and the sheaths of the shell canals (*a*), with their contents, are dragged out; *b*, the bulbous terminations of the contents of the canals; *c*, the connexion of these contents with the internal integument.

Fig. 3. From the flabellum of a Shrimp, the shell being removed:—*a*, the central mass, in which lie the nerves and vessels; *b*, external protecting process; *c*, hair-fibres; *d*, internal truncated extremities of their containing tubes.

* Philosophical Transactions, 1843, Part II.

Fig. 4. More highly magnified view of the outer extremities of three of the tubules, from fig. 3, with the tubular fibres passing through and issuing from them.

Fig. 5. From the end of the larger foot-jaw of the Shrimp:—*a*, the pulp, made up of tubular structure containing the hair-fibres, has been torn down from the shell, *b*; towards the lower part, on the right, the fibres are seen passing into the hair-canals.

Fig. 6. More highly magnified view of some of the preceding tubules, with their hair-fibres.

Fig. 7. Contents of the claw of the shrimp, the muscular tissue removed:—*a*, the hook-like pollex; *b*, the index; *c*, the central lamina on which the hair-fibres are supported; *d*, the nerve running up to the tubular structure from which the hair-fibres are issuing.

Fig. 8. The flabellum of the tail of the prawn, showing the tubular arrangement of the chorium, and the nerve (*a*) dividing and passing towards the tubules: at some parts the nerve can be traced to the extremities of the tubules, and may be seen to be connected with the hair-fibres.

ERRATUM.

Page 708, line 24, *for* February 1850, *read* May 1855.

INDEX

TO THE

PHILOSOPHICAL TRANSACTIONS

FOR THE YEAR 1858.

A.

Annelids, reproductive organs of the, 93.
Antimony, on the properties of electro-deposited, 185.
Arc of the Meridian, English, 787 (see CLARKE).
Astronomical vision, improvement of, with height, 477.

B.

BAKERIAN LECTURE. On the Stratifications and Dark Band in Electrical Discharges as observed in Torricellian Vacua, 1.
BATE (C. SPENCE). On the Development of Decapod Crustacea, 589.
BEER (Professor). Solution of POISSON's problem relative to magnetic induction in an ellipsoid, 555.
Blood-vessels, structure and functions of the, 653.
Boiler flues, resistance of, to collapse, 389 (see FAIRBAIRN).
BOWERBANK (Dr. J. S.). On the Anatomy and Physiology of the Spongiadæ. Part I.—On the Spicula, 279.—The spicula, 281; spicula of the skeleton, 286; connecting spicula, 289; prehensile, 291; defensive, 292; spicula of the membranes, 296; tension spicula, 297; retentive, 300; spicula of the sarcode, 306; spicula of the gemmules, 314; spicula, the positions of which are unknown, 321.
Brachiopoda, on the organization of the, 791 (see HANCOCK).
Brain, structure of the, 231 (see CLARKE).
BUCKTON (GEORGE BOWDLER). On the Isolation of the Radical, Mercuric Methyl, 163.—Decompositions of Mercuric Methyl, 166; Mercuric Ethyl, 168.

C.

Cairo, excavations near, 53 (see HORNER).

CALVERT (F. CRACE) and JOHNSON (RICHARD). On the Relative Power of Metals and Alloys to conduct Heat. Part I., 349.—Influence of molecular condition, 355; of crystallization, 355; of small amounts of impurities, 356; alloys containing an excess of the worse conducting metal, 360; alloys in which there is an excess of the good conductor, 365.

CAYLEY (ARTHUR). A Memoir on the Theory of Matrices, 17.

——————— A Memoir on the Automorphic Linear Transformation of a Bipartite Quadric Function, 39.

——————— Supplementary Researches on the Partition of Numbers, 47.

——————— A Fourth Memoir upon Quantics, 415.

——————— A Fifth Memoir upon Quantics, 429.—Addition, with Table by Mr. SALMON, 455.

——————— On the Tangential of a Cubic, 461.

Chondrosteus, 871.

CLARKE (Captain A. R.). Note on Archdeacon PRATT's Paper "On the Effect of Local Attraction in the English Arc," 787.

CLARKE (J. LOCKHART). Researches on the Intimate Structure of the Brain, Human and Comparative. First Series. On the Structure of the Medulla Oblongata, 231.—Medulla oblongata, 232; corpora pyramidalia anteriora, 235; corpora olivaria, 243; corpora olivaria of Mammalia and Birds, 245; structural changes in the upper part of the medulla, 247; origin of the nerves of the medulla oblongata, 252.

Conducting power of alloys for heat, 349 (see CALVERT); of metals for electricity, 383 (see MATTHIESSEN).

Contractions of the arteries, 607 (see LISTER).

Craters of elevation, 703 (see LYELL).

Crustacea, development of decapod, 589; structure and functions of the hairs of the, 895.

Cubic, on the tangential of a, 461.

Curves of the third order, 355.

D.

DALE (Rev. T. P.) and GLADSTONE (Dr. J. H.). On the Influence of Temperature on the Refraction of Light, 887.

DEBUS (Dr. H.). On the Action of Ammonia on Glyoxal, 205.—Glycosine, 205; glyoxaline, 207.

DE MORGAN (CAMPBELL). On the Structure and Functions of the Hairs of the Crustacea, 895.—Appendix, 901.

E.

EGERTON (Sir PHILIP DE MALPAS GREY). On CHONDROSTEUS, an Extinct Genus of the Sturionidæ, found in the Lias Formation at Lyme Regis, 871.

Egypt, researches relating to the geological history of the alluvial land of, 53 (see HORNER).

Etna, mode of origin of, 703 (see LYELL).

Euodyle, hydruret of, 202.

F.

FAIRBAIRN (WILLIAM). On the Resistance of Tubes to collapse, 389.—Experiments, resistance to collapse, 392; resistance of tubes to internal pressure, 401; generalization of the results of the experiments, formulæ, &c., 403; practical application to construction of the results of the experiments, 410.

FARADAY (Professor). Note from, to Professor TYNDALL, relative to the irregular fusibility of ice, 228.

Frog, on the cutaneous pigmentary system of the, 627.

G.

GASSIOT (JOHN P.). On the Stratifications and Dark Band in Electrical Discharges as observed in Torricellian Vacua, 1.—Action of a magnet on the inductive discharge, 13; note added, 14.

GLADSTONE (Dr. J. H.). See DALE.

Glyoxal, action of ammonia on, 205 (see DEBUS).

GORE (G.). On the Properties of Electro-deposited Antimony, 185.

H.

HANCOCK (ALBANY). On the Organization of the Brachiopoda, 791.—Muscular system, 795; alimentary system, 806; reproductive system, 816; circulatory and respiratory systems, 822; perivisceral chamber, 840; nervous system, 845; note added, 850.

HAUGHTON (Rev. S.). On the Physical Structure of the Old Red Sandstone of the County of Waterford, considered with relation to Cleavage, Joint Surfaces, and Faults, 333.—Description of the district, 333; faults, 334; joint planes, 336; cleavage planes, 338; observations tabulated, 340; note added, 348.

Heat, conduction of, by alloys, 349 (see CALVERT).

HORNER (LEONARD). An Account of some recent Researches near Cairo, undertaken with the view of throwing light upon the Geological History of the Alluvial Land of Egypt, 53 (for the contents, see p. 53).

I.

Ice, on some physical properties of, 211.

Inflammation, on the early stages of, 645 (see LISTER).

Irritants, effects of, upon the circulation and tissues, 658, 678.

J.

JOHNSON (RICHARD). See CALVERT.

K.

KIRKMAN (Rev. THOMAS P.). On the Partitions of the R-Pyramid, being the first class of R-gonous X-edra, 145.

L.

Lavas, structure of, 703 (see LYELL).
Linear transformations, 39 (see CAYLEY).
LISTER (JOSEPH). An Inquiry into the parts of the Nervous System which regulate the contractions of the Arteries, 607.
——————— On the Cutaneous Pigmentary System of the Frog, 627.
——————— On the Early Stages of Inflammation, 645.—Aggregation of the corpuscles of the blood, 647; structure and functions of the blood-vessels, 653; effects of irritants upon the circulation, 658; effects of irritants upon the tissues, 678; conclusion, 698.
LYELL (Sir CHARLES). On the Structure of Lavas which have consolidated upon steep slopes, 703 (for contents, see pp. 703–705).

M.

Magnetic induction of crystals, 543; of an isotropic ellipsoid, 554 (see PLÜCKER).
Magnetometer observations, 508.
Matrices, on the theory of, 17.
MATTHIESSEN (Dr. AUGUSTUS). On the Thermo-electric Series, 369.
——————————. On the Electric Conducting Power of the Metals, 383.
Medulla oblongata, structure of the, 231 (see CLARKE).
Megatherium, on the, 261.
Mercuric methyl, isolation of, 163 (see BUCKTON).
Meteorological observations on the Peak of Teneriffe, 512.
Moon and planets, appearance of, from a high station, 483.

O.

OWEN (Professor). Description of the Skull and Teeth of the *Placodus laticeps* (OWEN), with indications of other new species of *Placodus*, and evidence of the Saurian nature of that genus, 169.
——————————. On the MEGATHERIUM.—Part IV. Bones of the Anterior Extremities, 261.

P.

Partition of numbers, 47.
Placodus laticeps, &c., 169 (see OWEN).
PLÜCKER (Professor JULIUS). On the Magnetic Induction of Crystals, 543.—Direction in which biaxal crystals set, 545; three axes of magnetic induction, 547, 551, 554; magnetic axes, 550, 552, 554; on finite ellipsoids influenced by an infinitely distant pole, 554; experimental verification, 567; position of the three axes of magnetic induction with regard to the primitive form in crystals belonging to different systems, 580; note added, 584.
Polarization of the sky, 509.
Polyedra, on the theory of, 145 (see KIRKMAN).
PRATT (Archdeacon). See CLARKE.

Q.

Quantics, 415, 429.

R.

Radiation from the sun and sky, 495; of the moon, 500.
Refraction, lateral, 494.
Refraction of light, influence of temperature on the, 887.
Resistance of tubes to collapse, 389 (see FAIRBAIRN).
Rue, on the constitution of the essential oil of, 199.

S.

SALMON (Rev. G.). Calculation of HERMITE's 18-thic Invariant of a Binary Quintic, 455.
————. On Curves of the Third Order, 535.
Sandstone (*Old Red*) *of the County of Waterford*, 333 (see HAUGHTON).
SMYTH (Professor C. PIAZZI). Astronomical Experiment on the Peak of Teneriffe, carried out under the sanction of the Lords Commissioners of the Admiralty, 465.—Introductory matter, 465; deduced improvement of astronomical vision with height, 477; astronomical observations procured, 482; physical observations, 495; meteorological observations, 512.
Spectrum, lines in the, as seen from a high station, 503.
Spongiadæ, on the anatomy and physiology of the, 279 (see BOWERBANK).
Stratification of electric light, 1.
Sturionidæ, on an extinct genus of the, 871.

T.

Teneriffe, astronomical experiment on the Peak of, 465 (see SMYTH).
Thermo-electric series, on the, 369.
Tidal observations at Teneriffe, 532.
TYNDALL (Professor). On some Physical Properties of Ice, 211.—Note from Mr. FARADAY, 228.

W.

Waterford, old red sandstone of the county of, 333 (see HAUGHTON).
WILLIAMS (C. GREVILLE). On the Constitution of the Essential Oil of Rue, 199.
WILLIAMS (Dr. THOMAS). Researches on the Structure and Homology of the Reproductive Organs of the Annelids, 93.—Structure, 93; homology, 137.

Z.

Zodiacal light, 490.

LONDON:
PRINTED BY TAYLOR AND FRANCIS, RED LION COURT, FLEET STREET.

PRESENTS

RECEIVED BY

THE ROYAL SOCIETY,

WITH THE

NAMES OF THE DONORS.

From November 1857 to June 1858.

Presents.	Donors.
ACADEMIES and SOCIETIES.	
Aberdeen:—Sculptured Stones of Scotland. fol. *Aberdeen* 1856. (Printed for the Spalding Club).	The Club.
Amsterdam:—	
Verslagen en Mededeelingen der Koninklijke Akademie van Wetenschappen. Afdeeling Natuurkunde. 5de Deel. 2, 3, Stuk. 6de Deel. 1, 2, 3 Stuk. 8vo. *Amsterdam* 1856–1857.	The Academy.
——— Afdeeling Letterkunde, 2de Deel, 2, 3, 4 Stuk. 8vo. *Amsterdam* 1856, 1857.	———
Octaviæ Querela. Carmina, cuius Auctori Iohanni van Leeuwen. 8vo. *Amstelodami* 1857.	———
Basel:—Verhandlungen der Naturforschenden Gesellschaft. 4es Heft. 8vo. *Basel* 1857.	The Society.
Batavia:—	
Verhandelingen der Natuurkundige Vereeniging in Nederlandsch Indie. Deel 1, 1856; Deel 2, 1857. 4to. *Batavia*.	The Union.
——— Natuurkundige Tijdschrift. Deel 13. 8vo. *Batavia* 1857.	———
——— Tijdschrift voor Indische Taal-, Land- en Volkenkunde. Jahrgang 2; Afl. 1-6; Deel 4, Afl. 1-6; Deel 5, Afl. 1-6. 8vo. *Batavia* 1854-1856.	The Academy of Arts and Sciences.
Berlin:—	
Abhandlungen der Königlichen Akademie der Wissenschaften. *Aus dem Jahre* 1856. 4to. *Berlin* 1857.	The Academy.
Monatsbericht. May to December 1857; January to April 1858.	———
Physikalischen Gesellschaft. Die Fortschritte der Physik im Jahre 1855. *Jahrgang* XI.; *Abth.* 1. 8vo. *Berlin* 1858.	The Physical Society.
Bologna:—	
Memorie della Accademia delle Scienze dell' Istituto di Bologna. Tomo VII. 4to. *Bologna* 1856.	The Academy.
Rendiconto delle Sessioni 1855–1857. 8vo. *Bologna* 1856–1857.	———

PRESENTS.	DONORS.
ACADEMIES and SOCIETIES (*continued*).	
Bombay :—	
Transactions of the Geographical Society. Vol. XIII. (New Issue.) 8vo. *Bombay* 1857.	The Society.
Transactions of the Medical and Physical Society. No. 3. (New Series.) 8vo. *Bombay* 1857.	The Society.
Boston :—	
Memoirs of the American Academy of Arts and Sciences. Vol. VI. p. 1. 4to. *Cambridge and Boston* 1857.	The Academy.
Proceedings. Vol. III. Nos. 24–31. 8vo. *Boston.*	
Proceedings of the Boston Society of Natural History. Vol. V. Nos. 21–26. Vol. VI. Nos. 1–10. 8vo. *Boston* 1856–1857.	The Society.
Breslau :—	
Novorum Actorum Academiæ Cæsareæ Leopoldino-Carolinæ Naturæ Curiosorum. Voluminis Vicesimi tertii Supplementum. Sistens Revisionem Potentillarum Iconibus illustratam Auctore Christiano Lehmann. 4to. *Vratislaviæ et Bonnæ* 1856.	The Academy.
Vier und dreissigster Jahres-Bericht der Schlesischen Gesellschaft für vaterländische Kultur... im Jahre 1856. 4to. *Breslau.*	The Society.
Grundzüge der Schlesischen Klimatologie. 4to. *Breslau* 1857.	———
Brussels :—	
Mémoires Couronnés et autres Mémoires publiés par l'Académie Royale des Sciences. Tome VII. 8vo. *Bruxelles* 1858.	The Academy.
Bulletins. 26me année, 2me série. Tomes I. II. III. 8vo. *Bruxelles.* 1857.	———
Annuaire. 24me année. 12mo. *Bruxelles* 1858.	———
Der Naturen Bloeme van Jacob van Maerlant—voor de eerste mael uitgegeven door J. H. Bormans. Eerste Deel. 8vo. *Brussel* 1857.	———
Rymbybel van Jacob van Maerlant, met voorrede, &c.—voor de eerste mael uitgegeven door J. David. 8vo. *Brussel* 1858.	———
Caen :—Annuaire des Cinq Départements de l'Ancienne Normandie. 23me année. 8vo. *Caen, Paris* 1857.	L'Association Normande.
Calcutta :—Journal of the Asiatic Society of Bengal. Nos. 1–4, 1857. 8vo. *Calcutta* 1857.	The Society.
Cherbourg :—Mémoires de la Société Impériale des Sciences Naturelles. Tome IV. 8vo. *Paris, Cherbourg* 1856.	The Society.
Copenhagen :—	
Supplément aux Tables du Soleil, by P. A. Hansen. 4to. *Copenhague* 1857.	The Royal Society, Copenhagen.
Christiania :—	
A Silver Medal struck in honour of Christopher Hansteen (For. Mem. R.S.).	The Royal Norsk Frederick's University.
Beiträge zur Lateinischen Grammatik. Von L. C. M. Aubert. 8vo. *Christiania* 1856.	———
Det Kongelige Norske Frederiks Universitets Aarsberetning for 1855–1856. 8vo. *Christiania* 1857.	———
Generalberetning fra Gaustad Sindsygeasyl for Aaret 1856, ved Ole Sandberg, Direktor. 4to. *Christiania* 1857.	———
Index Scholarum in Universitate Regia Fredericiana, 27, 28, 29, &c. 4to. *Christiania* 1856–1857.	———

Presents.	Donors.
ACADEMIES and SOCIETIES (*continued*).	
Christiania:—	
Inversio Vesicæ Urinariæ, og Luxationes femorum congenitæ hos samme Individ, iagtagne af Lektor Voss. 4to. *Christiania* 1857.	The Royal Norsk Frederick's University.
Norges Skole System. Af Consulent Nissen. 8vo.	———
Norges Statistik, fremstillet ved M. Braun Tvethe. 8vo. *Christiania* 1848.	———
Nyt Magazin for Naturvidenskaberne. Bind. IX. 8vo. *Christiania* 1856–1857.	———
Observations sur les Phénomènes d'Erosion en Norvège, recueillies par J. C. Hörbye. 4to. *Christiania* 1857.	———
Om Giftermaal i Norge. Af Eilert Sundt. 8vo. *Christiania* 1855.	———
Om Sœdeligheds-Tilstanden i Norge. Af Eilert Sundt. 8vo. *Christiania* 1857.	———
Professor B. M. Keilhau's Biographie. Von ihm selbst. 8vo. *Christiania* 1857.	———
Quelques Observations de Morphologie Végétale faites au Jardin Botanique de Christiania par J. M. Norman. 4to. *Christiania* 1857.	———
Udtog af Norges Riges Historie, &c. Af Andreas Faye. 8vo. *Christiania* 1834.	———
Dijon:—	
Mémoires de l'Académie Impériale des Sciences, Arts et Belles Lettres. 2me série. Tome V. 8vo. *Dijon* et *Paris* 1857.	The Academy.
Description d'un nouveau Genre d'Édenté fossile renfermant plusieurs espèces voisines du Glyptodon. Par L. Nodot. Atlas. 4to.	———
Drontheim:—	
Det Norske Sprogs væsentligtte Ordforraad sammenlignet med Sanskrit og andre Sprog af samme Æt. Af C. A. Holmbœ. 4to. *Wien* 1852.	The Royal Norsk Scientific Society.
Fauna littoralis Norvegiæ von M. Sars. 1ste Lieferung. fol. *Christiania* 1846.	———
Gæa Norvegica. Von B. M. Keilhau. 4to. *Christiania* 1844.	———
Œuvres complètes de N. H. Abel, Mathématicien, avec des Notes et Développements, rédigées par ordre du Roi, par B. Holmbœ. 4to. *Christiania* 1839.	———
Ordbog over det Norske Folkesprag, af Ivar Aasen. 8vo. *Kristiania* 1850.	———
Dublin:—	
Catalogue of the Antiquities of Stone, Earthen, and Vegetable Materials, in the Museum of the Royal Irish Academy. By W. R. Wilde. 4to. *Dublin* 1857.	The Academy.
Journal of the Geological Society. Vol. VII. Pt. 5. 8vo. *Dublin* 1857.	The Society.
Journal of the Royal Dublin Society. Nos. 6–8. 8vo. *Dublin* 1857–1858.	The Society.
Proceedings of the Natural History Society of Dublin for the Session 1856–1857. 8vo. *Dublin* 1857.	The Society.
Edinburgh:—	
Transactions of the Royal Society. Vol. XXI. Part 4. 4to. 1857.	The Society.
Proceedings. Vol. III. No. 47. 8vo. *Edinburgh* 1857.	———
Transactions of the Scottish Arboricultural Society. Vol. I. Part 3. 8vo. *Edinburgh* 1858.	The Society.

Presents.	Donors.
ACADEMIES and SOCIETIES (*continued*).	
Edinburgh :—	
Transactions of the Royal Scottish Society of Arts. Vol. V. Part 1. 8vo. *Edinburgh* 1857.	The Society.
Catalogue of the Library of the Philosophical Institution. 8vo. *Edinburgh* 1857.	The Directors of the Institution.
Falmouth :—Royal Cornwall Polytechnic Society. Twenty-fourth Annual Report, 1856. 8vo. *Falmouth.*	The Society.
Göttingen :—Abhandlungen der Königl. Gesellschaft der Wissenschaften. 4to. *Göttingen* 1857.	The Society.
Hamburgh :—Abhandlungen aus dem Gebiete der Naturwissenschaften, herausgegeben von dem Naturwissenschaftlichen Verein. 3ter Band. 4to. *Hamburg* 1856.	The Union.
Lancashire and Cheshire :—Transactions of the Historic Society. Vol. IX. 8vo. *London* 1857.	The Society.
Lausanne :—Bulletin de la Société Vaudoise des Sciences Naturelles. Tom. IV. Nos. 34–37 ; Tome V. Nos. 38–43. 8vo. *Lausanne* 1854–1857.	The Society.
Leeds :—Thirty-seventh Report of the Council of the Leeds Philosophical and Literary Society, 1856–1857. 8vo. *Leeds* 1857.	The Society.
Leipzig :—	
Berichte über die Verhandlungen der Königlich Sächsischen Gesellschaft. Math.-Phys. Classe. 1 & 2. 8vo. *Leipzig* 1857.	The Society.
Elektrische Untersuchungen. 2te Abhandlung über die Thermo-elektrischen Eigenschaften des Boracites. Von W. G. Hankel. 8vo. *Leipzig* 1857.	———
Auseinandersetzung einer Zweckmässigen Methode zur Berechnung der Absoluten Störungen der Kleinen Planeten. 2te Abhandlung. Von P. A. Hansen. 8vo. *Leipzig* 1857.	———
Die Böhmischen Exulanten in Sachsen. Von C. A. Pescheck. 8vo. *Leipzig* 1857.	———
Lisbon :—	
Historia e Memorias da Academia Real das Sciencias de Lisboa. 2a serie. Tom. I.—III. 4to. *Lisboa* 1843–1856.	The Academy.
Memorias. Classe de Sciencias Moraes, Politicas e Bellas Lettras. Nova serie. Tomo I. Parte 1 & 2. 4to. *Lisboa* 1855.	———
———. Classe de Sciencias Mathematicas, Physicas e Naturaes. Nova serie. Tomo I. Parte 1 & 2. 4to. *Lisboa* 1854–1855.	———
Actas das Sessões. Tom. 1. Num. 1–8 ; Tom. II. Num. 1–6. Tom. III. Num. 1–3. *Lisboa* 1849–1851.	———
Annaes das Sciencias e Lettras : Sci. Math., Phys. &c. Tomo I. Março-Junho 1857. Sci. Mor. e Polit. &c. Tomo I. Março–Junho, 1857. 8vo. *Lisboa.*	———
Collecção de Noticias para a Historia e Geografia das Nações ultramarinas, que vivem nos Dominios Portuguezes, ou lhes são visinhas. Tomo VI. 8vo. *Lisboa* 1856.	———
Portvgaliae Monvmenta Historica a Saecvlo octavo post Christvm vsqve ad qvintvmdecimvm Jussv Academiae Scientiarvm Olisiponensis edita. Leges et Consvetvdines. Vol. I. Fasc. 1. Scriptores. Vol. I. Fasc. 1. fol. *Olisipone* 1856.	———

Presents.	Donors.
ACADEMIES and SOCIETIES (*continued*).	
Liverpool:—Proceedings of the Literary and Philosophical Society. No. 11.	The Society.
London:—	
British Architects. Papers read at the Royal Institute of British Architects, Session 1856–1857. 4to. *London* 1857.	The Institute.
List of Members and Report of Council, 1858.	———
British Association. Report of the Twenty-sixth Meeting. 8vo. *London* 1857.	The Association.
Board of Trade.—Meteorological Department. First Number of Meteorological Papers published by Authority of the Board of Trade. 4to. *London* 1857.	The Board of Trade.
Chemical Society. Quarterly Journal. Vol. X. Nos. 2 to 4. Vol. XI. No. 1. 8vo. *London* 1857–1858.	The Society.
Entomological Society. Transactions. New Series. Vol. IV. Parts 4–5. 8vo. *London* 1857.	The Society.
Geological Society. Quarterly Journal. Vol. XIII. Parts 2, 3, 4. Vol. XIV. Parts 1 & 2. 8vo. *London* 1857–1858.	The Society.
Geological Survey. Memoirs of the Geological Survey of Great Britain, and of the Museum of Practical Geology. Mineral Statistics of the United Kingdom of Great Britain and Ireland for the year 1856. By Robert Hunt, F.R.S. 8vo. *London* 1857.	The Museum.
——— Memoirs. Decade IX. 4to. *London* 1858.	———
Juridical Society. Papers. Vol. I. Parts 1–6. 8vo. *London* 1855–1858.	The Society.
Linnean Society. Transactions. Vol. XXII. Part 2. 4to. *London* 1857.	The Society.
——— Journal of the Proceedings. Vol. II. Nos. 5–8. 8vo. *London* 1857–1858.	———
Pathological Society. Transactions. Vol. VIII. 8vo. *London* 1857.	The Society.
Photographic Society. Journal. Nos. 56–65. 8vo. 1857–1858.	The Society.
Royal Agricultural Society. Journal. Vol. XVIII. 8vo. *London* 1857.	The Society.
Royal Astronomical Society. Memoirs. Vols. XXV. XXVI. 4to. *London* 1857–1858.	The Society.
——— Monthly Notices. Vols. XVI. XVII. 8vo. *London* 1856–1857.	———
Royal Geographical Society. Journal. Vol. XXVII. 8vo. *London* 1857.	The Society.
——— Proceedings. Vol. II. No. 2. 8vo. *London* 1858.	
Royal Institution. Notices of the Meetings of the Members. Part 7. Nov. 1856 to July 1857. 8vo. *London* 1857.	The Institution.
——— List of the Members, &c., with the Report of the Visitors for the year 1856. 8vo. *London* 1857.	———
——— A new Classified Catalogue of the Library of the Royal Institution of Great Britain, &c. By B. Vincent. 8vo. *London* 1857.	———
Royal Medical and Chirurgical Society. Transactions. Vol. XIV. 8vo. *London* 1857.	The Society.
——— Proceedings. Vol. I. No. 3. Vol. II. No. 1, 1858. 8vo. *London* 1858.	———
Royal Society of Literature. Transactions. Second Series. Vol. VI. Part 1. 8vo.	The Society.
Society of Antiquaries. Archæologia. Vol. XXXVII. 4to. *London* 1857.	The Society.
——— Proceedings. Vol. III. Nos. 43–46. 8vo.	———
——— List of Fellows, 1856–1857. 8vo.	———

Presents.	Donors.
ACADEMIES and SOCIETIES (*continued*).	
London:—	
Society of Arts. Journal. Nos. 229, 233 and 235–290. Vols. V. and VI. 1857–1858. 8vo. *London*.	The Society.
Statistical Society. Journal. Vol. XX. Parts 2–4. Vol. XXI. Part 1. 8vo. *London* 1857.	The Society.
——— List of Fellows. Session 1857–1858. 8vo. 1858.	———
United Service Institution. Journal. Vol. I. Nos. 1 & 4. Vol. II. No. 5. 8vo. *London* 1857–1858.	The Institution.
Zoological Society. Transactions. Vol. IV. Part 4. 4to. *London* 1857.	The Society.
——— Proceedings. Nos. 314–349. 8vo.	———
Madrid:—Memorias de la Real Academia de Ciencias. Tomo 4. 3ª Serie. Ciencias Naturales. Tomo II. Parte 2ª. 4to. *Madrid* 1857.	The Academy.
Manchester:—	
Memoirs of the Literary and Philosophical Society. Vol. XIV. Second Series. 8vo. *London* 1857.	The Society.
On the Microcosmic Salt, Acids, Bases, and Water, and a new and easy Method of Analysing Sugar. By J. Dalton. 8vo. *Manchester* 1840–1842.	The Society.
Meteorological Observations and Essays. Second Edition. 8vo. *Manchester* 1834.	———
A New System of Chemical Philosophy. Part 1. Second Edition. 8vo. *London* 1842.	———
——— Part 2. 8vo. *Manchester* 1810.	———
——— Vol. II. Part 1. 8vo. *Manchester* 1827.	———
Moscow:—Bulletin de la Société Impériale des Naturalistes de Moscou. Année 1856, Nos. 2, 3, 4. Année 1857, No. 1. 8vo. *Moscou* 1856–1857.	The Society.
Munich:—	
Abhandlungen der Königlich Bayerischen Akademie der Wissenschaften. Philosoph.-Philogischen Classe. 8ᵗᵉ Bandes, Abth. 1, 2. 4to. *München* 1856–1857.	The Academy.
Math. Phys. Classe. Band. 8, Abth. 1. 4to. *München* 1857.	———
Abhandlungen der Naturwissenschaftlich-Technischen Commission bei der Königl. Akad. der Wissenschaften in München. Erster Band. 8vo. *München* 1857.	———
Gelehrte Anzeigen. Band. 42–45. 4to. *München* 1856–1857.	———
Denkrede auf Christian Samuel Weiss. Von Dr. C. F. P. von Martius. 4to. *München* 1857.	———
Denkrede auf Johann Nepomuk Fuchs. Von F. von Kobell. 4to. *München* 1856.	———
Die Deutsche Politik König Heinrich I. Von F. Löher. 4to. *München* 1857.	———
Ueber den Anbau und Ertrag des Bodens im Königreiche Bayern. 1 Abtheilung. Von Dr. F. B. von Hermann. 4to. *München* 1857.	———
Ueber die Gründung der Wissenschaft altdeutscher Sprache und Literatur. Von Dr. Konrad Hofmann. 4to. *München* 1857.	———

Presents.	Donors.
ACADEMIES and SOCIETIES (*continued*).	
Naples:—	
Memorie della Reale Accademia delle Scienze. Vols. I. and II. 4to. *Napoli* 1857.	The Academy.
Rendiconto. Anno 5. 1856–1857. Nuova Serie. 4to. *Napoli*.	———
New York:—	
Bulletin of the American Geographical and Statistical Society. Vol. II. 8vo. *New York* 1857.	The Society.
On the Statistics and Geography of the Production of Iron, by A. S. Hewitt. 8vo. *New York* 1856.	———
The Growth of Cities, by H. P. Tappan. 8vo. *New York* 1855.	———
Access to an Open Polar Sea, &c., by E. K. Kane. 8vo. *New York* 1853. (Reprints from the Bulletin of the American Geog. Statist. Society.)	
Paris:—	
Mémoires présentés par divers Savants à l'Académie des Inscriptions et Belles Lettres de l'Institut Impérial de France. Première Série. Tom. V. Sujets divers d'Erudition. 4to. *Paris* 1857.	The Institute.
Mémoires. Académie des Inscriptions et Belles Lettres. Tome XXI. 4to. *Paris* 1857.	———
Comptes Rendus de l'Académie des Sciences. Tome XLVI. Nos. 1–23. 4to. *Paris* 1857–1858.	———
Tables. Tomes XLIV. XLV.	———
Annales des Mines. 5me Série. Tome X. Liv. 6. Tome XI. Liv. 1–3. Tome XII. Liv. 4–6. 8vo. *Paris* 1856, 1857.	L'École des Mines.
Archives du Muséum d'Histoire Naturelle. Tome IX. Liv. 4. 4to. *Paris* 1856, 1857.	The Museum.
Bulletin de la Société de Géographie. 4me Série. Tomes XIII. XIV. 8vo. *Paris* 1857.	The Society.
Bulletin de la Société Géologique de France. 2me Série. Tome XII. Feuilles 81-85. Tome XIII. Feuilles 31-56. Tome XIV. Feuilles 1-45. Tome XV. Feuilles 1-6. 8vo. *Paris* 1854–1858.	———
Annales Hydrographiques. Tomes XI. XII. No. 245. 8vo. *Paris* 1857.	Le Dépôt de la Marine.
Annuaire des Marées des Cotes de France pour l'An 1857. Par A. M. R. Chazallon. 8vo *Paris* 1857.	———
Considérations générales sur l'Océan Pacifique. Deuxième Edition. 8vo. *Paris* 1856.	———
Déscription des Iles et des Passages compris entre la partie nord de l'Ile Luçon et les Iles du Japon. (Extrait.) 8vo. *Paris* 1857.	———
Déscription Nautique de la Cote N. du Maroc. 8vo. *Paris* 1857.	———
Explication et Usage des Wind et Current Charts. 8vo. *Paris* 1857. (Extrait des Sailing Directions du Lieut Maury.)	———
Instructions Nautiques sur les Mers de l'Inde, par James Horsburgh, traduites de l'Anglais, en 1857, par M. Le Prédour. Tome II. 4to. *Paris* 1856.	———
Instructions pour entrer dans le Port d'Alexandrie. 8vo. *Paris* 1856. (Extrait.)	———
Instructions sur la Nouvelle-Calédonie, &c. 8vo. *Paris* 1857.	———
Manuel de la Navigation dans le Rio de la Plata, &c. 8vo. *Paris* 1857. (Extrait des Annales Hydrographiques.)	———

FRANKLIN INSTITUTE LIBRARY

Presents.	Donors.
ACADEMIES and SOCIETIES (*continued*).	
Paris:—	
Observations Chronométriques et autres faites en 1853, dans l'Archipel des Pomotous. 8vo. *Paris* 1857. (Extrait.)	Le Dépôt de la Marine.
Observations sur la Navigation des Paquebots qui traversent l'Atlantique. 8vo. *Paris* 1856. (Extrait.)	———
Phares des Mers du Globe, &c. 8vo. *Paris* 1856.	———
Supplément (No. 1) au Pilote de la Mer Baltique. 8vo. *Paris* 1857. (Extrait.)	———
Philadelphia:—	
Academy of Natural Sciences. Proceedings. Vol. VIII. Nos. 3–16. Title and Index to Vol. VIII. Vol. IX. Nos. 1–6. Act of Incorporation and By-Laws of the Academy. List of Members and Correspondents, from the Origin of the Society in 1812 to March 1, 1857.	The Academy.
Catalogue of Human Crania in the Collection of the Academy, by J. A. Meigs, M.D. 8vo. *Philadelphia* 1856-1858.	———
American Philosophical Society. Transactions. Vol. XI. New Series. Part 1. 4to. *Philadelphia* 1857.	The Society.
——— Proceedings. Vol. VI. Nos. 55, 56. 8vo. 1856.	———
Franklin Institute. Journal. Vol. XXXIV. and Vol. XXXV. Nos. 1–4. 8vo. *Philadelphia* 1857, 1858.	The Institute.
Rome:—Atti dell' Accademia Pontificia de' Nuovi Lincei. Anno VI. Sessione 1-2, 1856. Anno X. Sessione 1-5, 1857. 4to. *Roma*.	The Academy.
St. Louis:—Transactions of the Academy of Science. Vol. I. No. 1. 8vo. *St. Louis* 1857.	The Academy.
St. Petersburgh:—	
Mémoires de l'Académie Impériale des Sciences. 6me Série. Sciences Mathématiques, Physiques et Naturelles. Tome VIII. 1855. Tome IX. 4to. *St. Pétersbourg* 1857.	The Academy.
Sciences Politiques, Histoire, Philologie. Tome VIII. 4to. *St. Pétersbourg* 1855.	———
Mémoires présentés par Divers Savants. Tome VII. 4to. *St. Pétersbourg* 1854.	———
Bulletin de la Classe Physico-Mathématique. Tomes XII. XIII. XIV. XV. 4to. *St. Pétersbourg* 1854–1857.	———
Bulletin de la Classe Historico-Philologique. Tomes XI. XII. XIII. 4to. *St Pétersbourg* 1854–56.	———
Compte Rendu de l'Académie Impériale des Sciences, 1852–1855. 3 vols. 4to. *St Pétersbourg* 1853-1856.	———
Stockholm:—	
Berättelse om Botaniska Arbeten och Upptäckter under åren 1853 och 1854. 8vo. *Stockholm* 1856.	The Academy.
Års-Berättelse om Botaniska Arbeten för år 1852. *Stockholm* 1857.	———
Berättelse om Framstegen i Insekternas, &c. för 1853 och 1854. 8vo. *Stockholm* 1857.	———
Kongl. Vetenskaps-Akademiens Handlingar för år 1854. Sednare Afdelningen. 8vo. *Stockholm* 1856.	———

Presents.	Donors.
ACADEMIES and SOCIETIES (*continued*).	
Stockholm:—	
Kongliga Svenska Vetenskap-Akademiens Handlingar. *Ny Följd. Första Bandet. Första Häftet*, 1855. 4to. *Stockholm.*	The Academy.
Ofversigt af Kongl. Vetenskaps-Akademiens Förhandlingar. Trettonde Årgången, 1856. 8vo. *Stockholm* 1857.	———
Tal Om förflutna tiders Svenska Ordboksforetag. 8vo. *Stockholm* 1857.	———
Exposition des Opérations faites en Lapponie, pour la Détermination d'un Arc du Méridien, en 1801, 1802 et 1803, &c. Par J. Svanberg. 8vo. *Stockholm* 1805.	———
Surrey:—Collections of the Surrey Archæological Society. Vol. I. Part 2. 8vo. *London* 1858.	The Society.
Switzerland:—	
Nouveaux Mémoires de la Société Helvétique des Sciences Naturelles. 14 vols. Vols. I.–VI., VIII.–XV. 4to. *Neuchâtel* et *Zürich* 1837–1857.	The Society.
Eroffnungs-Reden, et Actes de la Société Helvétique. Réunions Annuelles. 35 vols. 1819-1856. 8vo. *St. Gallen, Basel, &c. &c.*	———
Toronto:—The Canadian Journal of Industry, Science, and Art. Nos. 8–13. New Series. 8vo. *Toronto* 1857–1858.	The Canadian Institute.
Toulouse:—	
Mémoires de l'Académie Royale des Sciences, Inscriptions et Belles Lettres. 3me Série. Tom. IV. Académie Nationale. Tom. V., VI. 8vo. *Toulouse* 1848, 1849, 1850.	The Academy.
Mémoires de l'Académie Impériale. 5me Série. Tome I. 8vo. *Toulouse* 1857.	———
Table Alphabétique des Matières contenues dans les Seize premiers tomes des Mémoires de l'Académie Impériale, &c. 8vo. *Toulouse* 1854.	———
Turin:—Memorie della Reale Accademia delle Scienze. Serie Seconda. Tomo XVI. 4to. *Torino* 1857.	The Academy.
Vienna:—	
Denkschriften der Kaiserlichen Akademie der Wissenschaften. Math. Natur. Classe. Bd. 12, 13. 4to. *Wien* 1856, 1857.	The Academy.
——— Phil. Hist. Classe. Bd. 8. 4to. *Wien* 1857.	———
Sitzungsberichte. Math. Natur. Classe. 20 Bd. 2 und 3 Heft. 21, 22, 23 Bd. und 24 Bd. Heft 1, 2. 8vo. *Wien* 1856, 1857.	———
Register. Band 11–20. 8vo. *Wien* 1856.	———
——— Phil. Hist. Classe. 20 Bd. 2 und 3. Heft. 21, 22 und 23. Bd. 1–4 Heft. 8vo. *Wien* 1856, 1857.	———
Register. Band 11–20. 8vo. *Wien* 1856.	———
Almanach der Akademie. Siebenter Jahrgang, 1857. 8vo. *Wien.*	———
Jahrbuch der K. K. Geologischen Reichsanstalt. 1856, VII. Jahrgang, No. 4. 1857, VIII. Jahrgang, No. 1. 4to. *Wien.*	The Institute.
Mittheilungen der K. K. Geographischen Gesellschaft. 1er Jahrgang, 1857. Heft 1. 4to. *Wien* 1857.	The Society.
Tageblatt der 32. Versammlung Deutscher Naturforscher und Aerzte in Wien im Jahre 1856. 4to. 1856. Nos. 1–8.	———
Washington:—	
Smithsonian Contributions to Knowledge. Vol. IX. 4to. *Washington* 1857.	The Smithsonian Institution

Presents.	Donors.
ACADEMIES and SOCIETIES (*continued*).	
Washington :—	
Tenth Annual Report of the Board of Regents. 8vo. *Washington* 1856.	The Smithsonian Institution.
Researches on the Ammonia-Cobalt Bases, by W. Gibbs, and F. A. Genth. 4to. *Washington* 1856.	———
Wisconsin :—	
An Address delivered before the Regents, Faculty, and Students of the University, &c., by D. Read, LL.D. 8vo. *Madison* 1857.	The State Historical Society of Wisconsin.
Annual Report of the Geological Survey of the State of Wisconsin. By J. G. Percival. 8vo. *Madison* 1856.	———
City of Watertown, Wisconsin, &c. 8vo. *Watertown* 1856.	———
Charter of the City of Madison. 8vo. *Madison* 1856.	———
First Annual Report of the Wisconsin Teachers' Association. 8vo. *Madison* 1854.	———
First and Second Annual Report and Collections of the State Historical Society of Wisconsin for the Years 1854 and 1855. Vols. I. and II. 8vo. *Madison* 1855–1856.	———
Four Maps and Plans of Wisconsin. *Madison* and *Milwaukee*.	———
First, Second and Third Annual Catalogue, &c. of the Milwaukee Female College. 8vo. *Milwaukee* 1853, 1856.	———
Inaugural Adress...before the Board of Regents of the State University, by E. S. Carr. 8vo. *Madison* 1856.	———
Madison, the Capital of Wisconsin, &c., compiled by Lyman C. Draper. 8vo. *Madison* 1857.	———
Milwaukee City Directory. 8vo. 1856, 1857.	
Ninth Annual Report of the Board of Regents of the University of Wisconsin. 8vo. *Madison* 1857.	———
Prairie du Chien, &c. 8vo. *Milwaukee* 1857.	———
Report on the Iron of Dodge and Washington Counties, State of Wisconsin. By J. G. Percival. 8vo. *Milwaukee* 1855.	———
Report of the Locating Survey of the St. Croix and Lake Superior Railroad. 8vo. *Madison* 1856.	———
Second Annual Report of the Board of Education, &c. 8vo. *Madison* 1857.	———
Seymour's Madison Directory. 8vo. *Madison* 1855.	———
Transactions of the Wisconsin State Agricultural Society. Vols. II. & III. 8vo. *Madison* 1853, 1854.	———
The History of Wisconsin. In three parts: Historical, Documentary, and Descriptive. By W. R. Smith. Part 1. Historical. Vol. I. Part 2. Documentary. Vol. III. 8vo. *Madison* 1854.	———
Würzburg :—	
Verhandlungen der Physicalisch-Medicinischen Gesellschaft. 7er Bd. 3er Heft 8er Bd. 1, 2, 3 Heft. 8vo. *Würzburg* 1857, 1858.	The Society.
Sitzungsberichte für das Gesellschaftsjahr 1856. 8vo.	
Utrecht :—Meteorologische Waarnemingen in Nederland en zijne Bezittingen, &c., by Dr. F. W. C. Krecke. With Report. Obl. 4to. *Utrecht* 1857.	The Royal Netherlands Meteorological Institute.
Yorkshire :—Report of the Proceedings of the Geological and Polytechnic Society of the West Riding of Yorkshire, 1856, 1857. 8vo. *Leeds* 1857.	The Society.

Presents.	Donors.
AIRY (G. B., F.R.S.) Astronomical and Magnetical and Meteorological Observations made at the Royal Observatory, Greenwich, in the Year 1856. 4to. *London* 1858.	The Admiralty.
ANDREW (W. P.) The Indus and its Provinces, &c. &c. 8vo. *London*.	The Author.
ANGHERA (Rev. D.) Misura esatta del Cerchio ovvero la sua Quadratura, &c. 12mo. *Malta* 1857.	The Author.
——— Quadrature of the Circle, &c. (translation of the above) 12mo. *Malta* 1858.	———
ANONYMOUS:—	
Addresses delivered on different public Occasions, by H.R.H. The Prince Albert, &c. &c. Published by the Society of Arts. 4to. *London* 1857.	The Editor.
Almanaque Náutico parael año 1858. 8vo. *Cádiz* 1856.—para el año 1859. 8vo. *Cádiz* 1857.	The Observatory of San Fernando.
Astronomische Beobachtungen auf der Königlichen Universitäts-Sternwarte zu Königsberg. Fol. *Königsberg* 1857.	The Observatory.
Biographical Notice of the late Thomas Thomson, M.D., F.R.S. 8vo. *Glasgow* 1857.	
Catalogue of the New York State Library, 1855. 2 Vols. 8vo. *Albany* 1856.	The Trustees.
Circular to the Boards of Senior County Grammar Schools in Upper Canada, on Meteorological Observations; with a Map showing the proposed Meteorological Stations. *Toronto* 1857.	The Education Office, Toronto.
Documents and Proceedings connected with the Donation of a Free Public Library and Museum, by William Brown, Esq., M.P. to the Town of Liverpool. *Printed for private distribution.* 8vo. *Liverpool* 1858.	Dr. Hume.
Documents relating to the Colonial History of the State of New York; procured in Holland, England, and France. By J. R. Brodhead, Agent. Edited by E. B. O'Callaghan. Vols. I., V., VI., VII., IX. 4to. *Albany* 1855, 1856.	The Legislature of the State of New York.
Eighteenth Annual Report of the Registrar-General of Births, Deaths, and Marriages in England. 8vo. *London* 1857.	The Registrar-General.
Flora Batava. Afl. 182, 183. 4to. *Amsterdam*.	His Majesty the King of the Netherlands.
Fourth Report of the Post-Master General on the Post Office. 8vo. *London* 1858.	Rowland Hill, Esq., F.R.S.
Geological Papers on Western India, including Cutch, Sinde, and the South-east Coast of Arabia, &c. Edited for the Government by H. J. Carter. 8vo. *Bombay* 1857: and Atlas. Oblong fol. *Bombay* 1857.	The Directors of the Hon. East India Company.
Geological Survey of Canada. Report of Progress for the Years 1853, 1854, 1855, 1856. 8vo. *Toronto* 1857.	Sir W. E. Logan, F.R.S.
Plans of various Lakes and Rivers between Lake Huron and the River Ottawa, to accompany the Geological Reports, &c. 4to. *Toronto* 1857.	———
Memorial of the Inauguration of the Statue of Franklin. (Prepared and Printed by Authority of the City Council.) 4to. *Boston* 1857.	The Public Library, Boston, U.S.
Mortality of the British Army, at Home and Abroad, and during the Russian War, as compared with the Mortality of the Civil Population in England. (Reprinted from the Report of the Royal Commission.) fol. *London* 1855.	
Observations Météorologiques faites à Nijné-Taguilsk. Résumé des dix Années 1845–1854 et Années 1855 et 1856. 8vo. *Paris* 1857, 1858.	The Prince Demidoff.

Presents.	Donors.
ANONYMOUS (*continued*).	
Ophthalmic Hospital Reports, and Journal of the Royal London Ophthalmic Hospital. Edited by J. F. Streatfield. 8vo. *London* 1857.	The Editor.
Quarterly Return of Marriages, Births, and Deaths. Nos. 35, 36, 1857. 37, 1857.	The Registrar-General.
Rapport sur l'Exposition Universelle de 1855. 8vo. *Rouen* 1856.	Mons. E. Burel.
Report of the Commission of Patents for the Year 1855. Arts and Manufactures. Vols. I. and II. 8vo. *Washington* 1856. Agriculture. 8vo. *Washington* 1856.	The United States' Government.
Report on Metropolitan Drainage. fol. *London* 1857.	Captain Galton.
Report of the Secretary of War on the Harbours, &c. in Wisconsin, Illinois, Indiana, and Michigan. With 7 Maps. 8vo. *Washington* 1856.	Colonel Graham, U.S.A.
Report of the Superintendent of the Coast Survey, 1855. 4to. *Washington* 1856.	Professor A. D. Bache.
Report of the Twenty-Fifth Annual Meeting of the Literary Association of the Friends of Poland. 8vo. *London* 1857.	The Association.
Tenth Annual Report of the Board of Agriculture of the State of Ohio, for the Year 1855.	The Board.
The American Catalogue of Books, or English Guide to American Literature, &c. 8vo. *London* 1856.	Messrs. Low and Son, Publishers.
The Entomologist's Annual for 1858. 8vo. *London* 1858.	The Editor.
The London University Calendar, 1858. 8vo. *London*.	The University.
The Royal Gallery of Art. Parts XXIII. to XXXI. fol. *London* 1857, 1858.	S. C. Hall, Esq.
Ueber die Temperatur der Quellen von Kremsmünster. 8vo. *Wien*.	The Author.
What is the best Unit of Length? An Inquiry addressed to the International Association, &c. 8vo. *London* 1858.	J. Yates, Esq. F.R.S.
BATEMAN (J. F.) Reports on the Supply of Water to the City of Glasgow. 8vo. 1853–1855.	The Author.
BELANGER (J. B.) Théorie de la Résistance et de la Flexion Plane des Solides dont les Dimensions transversales sont petites relativement à leur Longueur. 8vo. *Paris* 1858.	The Author.
BIOT (J. B., For. Mem. R.S.) Lettre à M. de Falloux, sur M. le Baron Cauchy. 8vo. *Paris* 1857. (Extrait du Correspondant).	The family of Baron Cauchy.
BLOXAM (T.) On the Composition of the Building Sandstones of Craigleith, Binnie, Gifnock, and Partick Bridge. With a Preliminary Note by G. Wilson, M.D. 8vo. *Edinburgh* 1858. (From Proceedings Roy. Soc. Edin.)	The Author.
BÖHM (J. G.) and KARLINSKI (F.) Magnetische und Meteorologische Beobachtungen zu Prag. 16er Jahrgang. 4to. *Prag*. 1857.	The Observatory.
BRACHET (A.) Micrographie. Avertissement sur la Seconde Edition de la Notice du Meilleur Microscope dioptrique, &c. &c. 8vo. *Paris* 1857.	The Author.
BROUN (J. A., F.R.S.) Report on the Observatories of His Highness the Rajah of Travancore at Trevandrum, and on the Agustier Peak of the Western Ghats. 8vo. *Trevandrum* 1857.	The Author.
BROWNE (ROBERT.) Methods, Propositions, and Problems, for finding the Latitude...and the Longitude at Sea, &c. 8vo. *London* 1714.	A. de Morgan, Esq.
——— The Case of Robert Browne, relating to his Discovery of the Longitude at Sea, by Celestial Observations. 8vo. *London* 1732. (This book, which had formerly been presented to the Royal Society, and afterwards lost, is now again presented with notes by Mr. de Morgan.)	———

Presents.	Donors.
BRUGNOLI (G.) Bibliografia Italiana delle Scienze Mediche. Serie prima. Vol. I. Disp. 1 & 2. 8vo. *Bologna* 1858.	The Editor.
BRUNI (A.) Descrizione Botanica delle Campagne di Barletta. 8vo. *Napoli* 1857.	The Author.
BUIST (G., F.R.S.) Corrections of a few of the Errors contained in Sir William Napier's Life of his Brother, Sir Charles Napier, in so far as they affect the Press of India. 8vo. *London* 1857.	The Author.
BURT (T. S., F.R.S.) Miscellaneous Papers on Scientific Subjects, &c. Vol. II. 8vo. *London* 1858.	The Author.
CAMPBELL (H. F.) Essays on the Secretory and the Excito-Secretory System of Nerves in their Relations to Physiology and Pathology. 8vo. *Philadelphia* 1857.	The Author.
CARPENTER (W. B., F.R.S.) The Microscope and its Revelations. Second Edition. 8vo. *London* 1857.	The Author.
CARRINGTON (R. C.) A Catalogue of 3735 Circumpolar Stars observed at Redhill, in the Years 1854, 1855 and 1856, and reduced to Mean Positions for 1855·0. Printed at the Public Expense. fol. *London* 1857.	The Lords of the Admiralty.
CASTORANI (R.) Mémoire sur les Causes de la Cataracte lenticulaire. 8vo. *Paris* 1857.	The Author.
——— Mémoire sur la Photophobie. 8vo. *Paris* 1856. (Extraits de la Gazette Hebdom., &c.)	The Author.
——— Note sur un nouvel Instrument destiné à faciliter plusieurs des opérations qui se pratiquent sur les yeux et notamment l'Opération de la Cataracte. 4to. *Paris* 1856.	The Author.
——— Mémoire sur le Strabisme. 4to. *Paris* 1856. (Extraits des Comptes Rendus.)	———
CHALLIS (Rev. J., F.R.S.) Astronomical Observations made at the Observatory of Cambridge. Vol. XVIII. 4to. *Cambridge* 1857.	The Syndicate of the Observatory.
CIALDI (A.) Risultati di Studii idrodinamici nautici e commerciali sul Porto di Livorno, &c. 8vo. *Firenze* 1853.	The Author.
——— Appendice Seconda. 8vo. *Roma* 1855.	———
——— Sul Porto-Canale di Pesaro. 8vo. *Roma* 1856.	———
——— Cenni sul Moto Ondoso del Mare e sulle Correnti di esso. 4to. *Roma* 1856.	———
COLLIER (C., F.R.S.) The History of the Plague of Athens; translated from Thucydides, with Remarks explanatory of its Pathology. 8vo. *London* 1857.	The Author.
D'ARCHIAC (—). Notice Biographique sur Mercier de Boissy. 8vo. *Paris* 1856.	The Author.
——— Notice sur la Vie et les Travaux de Jules Haime. 8vo. *Paris* 1856.	———
DAUBENY (C., F.R.S.) Lectures on Roman Husbandry, delivered before the University of Oxford, &c. 8vo. *Oxford* 1857.	The Author.
DAUBRÉE (—). Observations sur le Métamorphisme et Recherches Expérimentales sur quelques-uns des Agents qui ont pu le produire. 8vo. *Paris* 1858.	The Author.
——— Recherches expérimentales sur le Striage des Roches. 8vo. *Paris* 1858. (Extraits des Annales des Mines.)	———
DE LA RIVE (A., For. Mem. R.S.) A Treatise on Electricity, in Theory and Practice. Vol. III. 8vo. *London* 1858.	The Author.
——— Excerpt from De la Rive's Electricity. Vol. III. 1858. Mr. C. V. Walker's Train-Signalling System. 8vo.	C. V. Walker, Esq., F.R.S.

Presents.	Donors.
DE MORGAN (A.) On the Beats of Imperfect Consonances. 4to. *Cambridge* 1858. (From the Trans. Cam. Phil. Soc.)	The Author.
DESLONGCHAMPS (E.) Déscription des Couches du Système oolithique inférieur du Calvados, suivie d'un Catalogue déscriptif des Brachiopodes qu'elles renferment. 8vo. *Caen* 1857.	The Author.
DICKSON (W.) The Annual Address of the Berwickshire Naturalists' Club. Sep. 24, 1857. 8vo. *Alnwick* 1857.	The Club.
DUNDONALD (Earl of.) Brief Extracts from Memoranda on the Use, Properties, and Products of the Bitumen and Petroleum of Trinidad. fol. *London* 1857.	The Author.
DUPREZ (F.) Statistique des Coups de Foudre qui ont frappé des Paratonnerres, &c. 4to. *Bruxelles*. 1857. (Extrait des Mém. Acad. Roy. de Belgique.)	The Author, per Sir W. S. Harris, F.R.S.
ENCKE (J. F., For. Mem. R.S.) Berliner Astronomisches Jahrbuch für 1860. 8vo. *Berlin* 1857.	The Author.
ERDMANN (A.) Om de Iakttagelser öfver Vattenhöjdens och Vindarnes Förändringar, &c. 4to. *Stockholm* 1856.	The Author.
——— Några Ord till Belysning af den Geologiska Kartan öfver Fyris-äns Dalbäcken. 8vo. *Stockholm* 1857. (With a coloured geological Map.)	———
ESCHER (P.) Begründung der wichtigsten Gesetze der allgemeinen Arithmetik 8vo. *Stuttgart* 1857.	The Author.
——— Geometric des Raums. 8vo. *Stuttgart* 1853.	———
——— Leichtfassliche Anleitung durch Raisonnement Münz-, Wechsel-, Maass- und Gewichtsrechnungen, u.s.w. 8vo. *Stuttgart* 1857.	———
EVEREST (R.) Statistical Details respecting the Republic of Lubeck, compared with those of some other European States. 8vo.	The Author.
——— Sequel to the Statistical Details, &c.	———
FAIVRE (E.) Etudes sur l'Histologie comparée du Système nerveux chez quelques Animaux Inférieurs. 4to. *Paris* 1857.	The Author, per The Lord Brougham, F.R.S.
——— Thèse pour le Doctorat en Médecine. Des Granulations Méningiennes. 4to. *Paris* 1853.	———
——— Du Cerveau des Dytisques, considéré dans ses rapports avec la Locomotion. 4to. *Paris* 1857. (Extrait des Comptes Rendus. Tome XLIV.)	———
——— Études sur le Conarium et les Plexus choroïdes chez l'Homme et les Animaux. 8vo. (Extrait des Annales des Sciences Naturelles. Tomo VII. 4me Série.)	———
——— Études sur la Constitution chimique des Élémens et des Tissus nerveux chez la Sangsue médecinale. 8vo. *Paris* 1857. (Extrait des Archives Générales de Médecine.)	———
FERGUSSON (E. F. T.) Magnetical and Meteorological Observations made at the Hon. East India Company's Observatory, Bombay, in the Year 1856. 4to. *Bombay* 1857.	The Directors of the Hon. East India Company.
FONTANA (C.) Calcoli ed Osservazioni in Base alle quali fu trovata la Direzioni e Locomozione degli Urani (Aerostati-Locomota). 8vo. *Milano*.	The Author.
GANT (F. J.) Evil Results of over-feeding Cattle. A New Inquiry, &c. 8vo. *London* 1858.	The Author.
GILLISS (J. M.) The U.S. Naval Astronomical Expedition to the Southern Hemisphere, &c. Vol. VI. Magnetical and Meteorological Observations. 4to. *Washington* 1856.	Lieut. Gilliss, U.S.N.

Presents.	Donors.
GLOESENER. Télégraphe à Aiguille perfectionné. 8vo. *Liège.*	The Author.
GLUGE (T.) et D'UDEKEM (J.) De quelques Parasites végétaux développés sur des Animaux Vivants. 8vo.	The Authors.
GLUGE (T) De l'Influence des Académies sur le Progrès des Sciences. 8vo. *Bruxelles* 1857. (Extraits des Bulletins.)	The Author.
GRAY (Maria Emma) Figures of Molluscous Animals, selected from various Authors. Vol. V. Conchifera and Brachiopoda. 8vo. *London* 1857.	The Authoress.
GRIFFIN (J. J.) The Radical Theory of Chemistry. 8vo. *London* 1858.	The Author.
GUEST (E., F.R.S.) An Essay on the Four Roman Ways. 8vo.	The Author.
HANSEN (P. A., For. Mem. R.S.) Tables de la Lune, construites d'après le Principe Newtonien de la Gravitation Universelle. (Imprimés au frais du Gouvernement Britannique.) 4to. *Londres* 1857.	Her Majesty's Government.
HARTNUP (J.) On the Importance of testing Chronometers before they are used at Sea, &c. 8vo. *Liverpool* 1857.	The Author.
——— On the Method of testing Marine Meteorological Instruments, recently introduced at the Liverpool Observatory. 8vo. *Liverpool* 1856.	———
——— Results deduced from Observations taken with the Self-registering Anemometer and Rain-Gauge, &c. 8vo. *Liverpool* 1856. (From the Transactions of the Historic Society of Lancashire and Cheshire.)	———
——— On controlling the Movements of Ordinary Clocks by Galvanic Currents. 8vo. *Liverpool* 1857. (Read before the British Association, September 1857.)	———
HENNESSY (H.) On the Physical Structure of the Earth. (From the Atlantis for January 1858.) 8vo.	The Author.
HOGG (J., F.R.S.) Address to the Members of the Tyneside Naturalists' Field Club, April 4, 1857. 8vo. *Newcastle-upon-Tyne* 1857.	The Author.
——— Sketches of Kertch, its larger Tumuli, and some other Remains. 8vo. *London* 1857. (From the Trans. Roy. Soc. Lit.)	———
HORSFIELD (T., F.R.S.) and MOORE (F.) A Catalogue of the Lepidopterous Insects in the Museum of the Hon. East India Company. Vol. I. 8vo. *London* 1857.	The Directors of the Hon. East India Company.
HOSKING (W.) Some Observations upon the recent Addition of a Reading Room to the British Museum. fol. *London* 1858.	The Author.
HOUZEAU (J. C.) Histoire du Sol de l'Europe. 8vo. *Bruxelles* et *Paris* 1857.	The Author.
JACOB (W. S.) and WORSTER (W. K.) Meteorological Observations made at the Meteorological Bungalow on Dodabetta, in the Years 1851-55. 4to. *Madras* 1857.	The Directors of the Hon. East India Company.
JENYNS (Rev. L.) Observations in Meteorology; relating to Temperature, the Winds, &c. 8vo. *London* 1858.	The Author.
JOHNSON (M. J., F.R.S.) Astronomical and Meteorological Observations made at the Radcliffe Observatory, Oxford, in the Year 1855. 8vo. *Oxford* 1856.	The Radcliffe Trustees.
JOLY (N.) et FILHOL. Recherches sur le Lait. 4to. *Bruxelles* 1856.	The Authors.
JONES (Rev. G.) Observations on the Zodiacal Light, made chiefly on Board the United States' Steam Frigate Mississippi, during her late Cruise in Eastern Seas, and her Voyage homeward, &c. (Being Vol. III. of the United States' Japan Expedition.) 4to. *Washington* 1856.	The U.S. Navy Department.

Presents.	Donors.
JOURNALS:—	
Cosmos. Vol. X. Liv. 23, 24, and Table Alphabétique; Vol. XI. Liv. 1-26; Vol. XII. Liv. 1-23. 8vo. *Paris*.	Mons. l'Abbé Moigno.
Journal of the Indian Archipelago. New Series, Vol. II. Nos. 1-3. 8vo. *Singapore* 1857.	The Editor.
The American Journal of Science and Arts. Vol. XXIV. Nos. 70 & 72; Vol XXV. 8vo. *Newhaven*, 1857-58.	The Editors.
The Asylum Journal of Mental Science. Vol. III. No. 22; Vol. IV. Nos. 23-25. 8vo. *London*.	The Editor.
The Athenæum. June to December 1857; January to May 1858.	The Editor.
The Atlantis: a Register of Literature and Science. Conducted by Members of the Catholic University of Ireland. No. 1, Jan. 1858. 8vo. *London* 1858.	The Editors.
The Builder. Vols. XV. and XVI. Nos. 749-800.	The Editor.
The Civil Engineer and Architect's Journal. August 1857. 4to.	The Editor.
The Literary Gazette. June to December 1857; January to May 1858.	The Editor.
The Philosophical Magazine. July to December 1857; January to June 1858. 8vo.	Messrs. Taylor and Francis.
The Pick and Gad: a Monthly Record of Mining and its allied Sciences and Arts. Conducted by Whitton Arundell. No. 1. 8vo. *London* 1857.	The Editor.
KÖLLIKER (A.) Untersuchungen zur vergleichenden Gewebelehre angestellt in Nizza im Herbste 1856. 8vo.	The Author.
KUPFFER (A. T.) Annales de l'Observatoire Physique central de Russie. Année 1854, Parts 1 & 2. 4to. *St. Pétersbourg* 1856.	The Observatory.
LAMONT (J., For. Mem. R.S.) Annalen der Königlichen Sternwarte bei München. Band 9. 8vo. *München* 1857.	The Observatory.
Resultate aus den an der Königl. Sternwarte veranstalteten Meteorologischen Untersuchungen, u.s.w. 4to. *München* 1857. (Aus den Abhandl. der K. Bayer. Akad.)	The Observatory.
LEA (I.) Description of New Species of Exotic Uniones, Peristomata, Melaniana, Naiades, &c. 8vo. *Philadelphia* 1857. (Extracts from Proceedings Acad. Nat. Sci. Philad.)	The Author.
——— Observations on the Genus Unio. Vol. VI. Part 1. 4to. *Philadelphia* 1857.	———
LE CANU (L. R.) Souvenirs de M. Thénard. 8vo. *Paris* 1857.	The Author.
LEE (Dr. R., F.R.S.) A Treatise on the Employment of the Speculum in the Diagnosis and Treatment of Uterine Diseases: with Three Hundred Cases. 8vo. *London* 1858.	The Author.
LE HON (H.) Périodicité des Grands Déluges résultant du mouvement graduel de la ligne des Apsides de la Terre. 8vo. *Paris* 1858. (Extrait des Mém. de la Soc. des Sciences de Hainaut.)	The Author.
LE VERRIER (U. J., For. Mem. R.S.) Annales de l'Observatoire Impérial de Paris. Tomes I. II. III. 4to. *Paris* 1855-57.	The Observatory, Paris.
——— Observations. Tome I. 4to. *Paris* 1858.	———
Atlas Ecliptique. Cartes, No. 4, 13, 51, 63, 64, 72. Par M. Chacornac.	———
LISSAJOUS (J.) Mémoire sur l'Étude Optique des mouvements vibratoires. 8vo. *Paris* 1857. (Extrait des Ann. de Chim. 3me Série, tom. li.)	The Author.
LOWE (E. J.) A Natural History of Ferns, British and Exotic. Parts 37-62. 8vo. *London* 1857-58.	The Author.

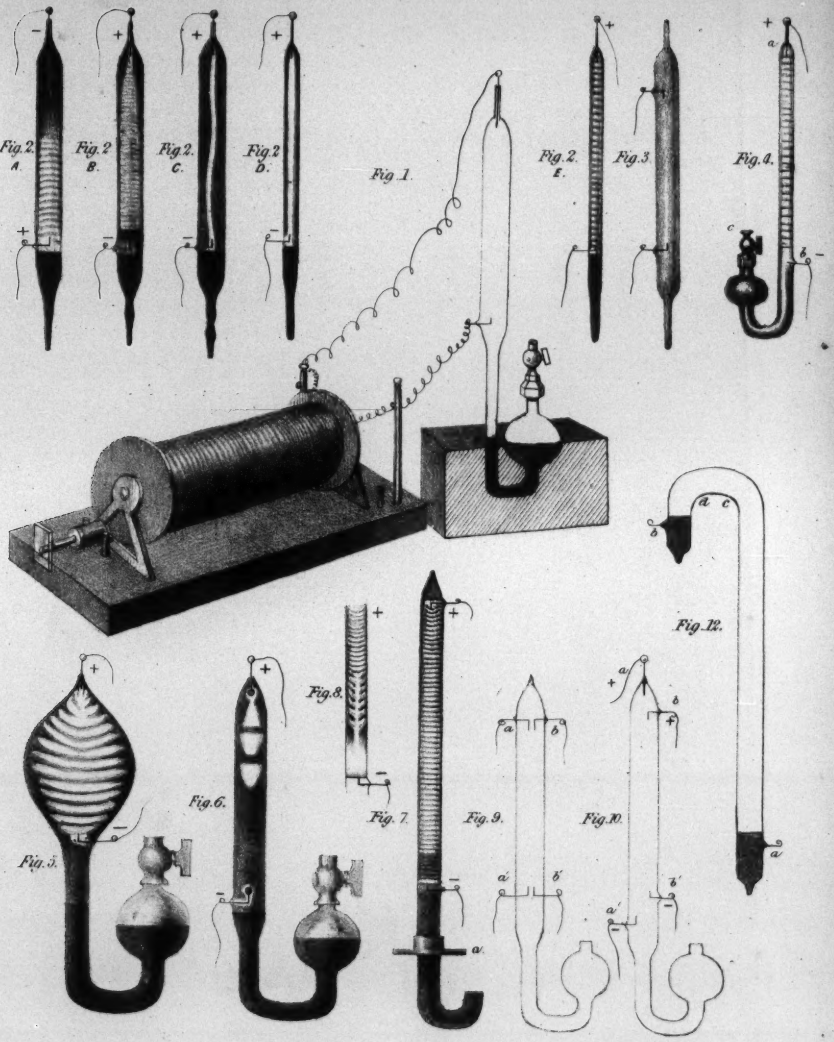
Presents.	Donors.
LOWE (E. J.) A Natural History of British Grasses. Parts 4–15. 8vo. *London* 1857-58.	The Author.
LUBBOCK (J.) Description of Eight New Species of Entomostraca found at Weymouth. 8vo. *London* 1857.	The Author.
——— An Account of the Two Methods of Reproduction in Daphnia, and of the Structure of the Ephippium. 4to. (Excerpt from Phil. Trans. 1857.)	The Author.
LUTHER (E.) and WICHMANN (M.) Astronomische Beobachtungen auf der Königlichen Universitäts Sternwarte zu Königsberg. 30ste Abth. fol. *Königsberg* 1857.	The Observatory.
MAHMOUD-EFFENDI. Mémoire sur l'État actuel des Lignes Isocliniques et Isodynamiques dans la Grande Bretagne, la Hollande, la Belgique et la France. 4to *Bruxelles*. (Extrait des Mém. de l'Acad. Roy. de Belgique.)	The Author, per T. Graham, Esq., F.R.S.
MALLET (R., F.R.S.) On the Molecular Constitution of the Metals of Ordnance, as affecting its Construction and Wear in Service. 8vo. *London* 1857.	The Author.
MAPS, CHARTS, ENGRAVINGS, &c.:—	
179 Charts, published by the Dépôt général de la Marine.	Le Dépôt de la Marine.
Map of the Maritime County of Mayo, in Ireland, &c. Commenced in 1809, and finished in 1817. By William Bald, Esq., F.R.S.E. 1830. Twenty-five Sheets.	Mrs. Bald.
7 Maps: Grand River, Chicago, St. Joseph, Sheboygan, and Manitowoc Harbours. Published by the United States' Government.	The U.S. Navy Department.
Mouths of the Parana and Uruguay. Sheet No. 1. 1855.	———
Track Survey of the River Paraguay. Sheets 10–15. 1855.	———
Track Survey of the River Parana. Sheet No. 2. 1855.	———
Track Survey of the Rivers Salado, Parana, and Colastiné. 1855.	———
MARTINS (C.) Nouvelle Comparaison des Membres Pelviens et Thoraciques chez l'Homme et chez les Mammifères déduites de la Torsion de l'Humerus. 4to. *Montpellier* 1857.	The Author.
MARTIUS (C. F. P. von, For. Mem. R.S.) Ueber die Pflanzen-Namen in der Tupi Sprache. 4to *München* 1858.	The Author.
——— Denkrede auf J. S. C. Schweigger. 4to. *München* 1858. (From the Bulletin of the Academy.)	———
MATTEUCCI (C.) Cours d'Electro-Physiologie. 8vo. *Paris* 1858.	The Author.
MAURY (M. F.) Astronomical Observations made during the Year 1848, at the U. S. N. Observatory, Washington. Vol. IV. 4to. *Washington* 1856.	The Observatory.
MIDDLETON (J.) A Syllabus of the Lectures upon Experimental Philosophy delivered at the Agra College. Third Edition. 8vo. *London* 1857.	The Author.
MIERS (J., F.R.S.) Illustrations of South American Plants. Vol. II. 4to. *London* 1849-57.	The Author.
MILLIGAN (J.) Vocabulary of Dialects of Aboriginal Tribes of Tasmania. fol. *Tasmania*.	The Author.
MINANGOUIN (—). Compte Rendu sur l'Agriculture de la Colonie de Mettray. 8vo. *Paris* 1857.	Mons. T. Brame.
MINERVINI (G.) Bulletino Archeologico Napolitano. Anno quinto. 4to. *Napoli* 1857.	The Editor.
MULDER (G. J.) Scheikundige Verhandelingen en Onderzoekingen. Tweede Deel. 1ste Stuk. 8vo. *Rotterdam* 1858.	The Home Department, Government of the Netherlands.

Presents.	Donors.
MULDER (G. J.) Scheikundige Verhandelingen et Onderzoekingen. De Essayeer-Methode van het Zilver; De Bewaring der Levens middelen; Het Bier. Eerste Deel. 8vo. *Rotterdam* 1857.	The Home Department, Government of the Netherlands.
——— The Chemistry of Wine. Edited by H. Bence Jones, M.D., F.R.S. 8vo. *London* 1857.	The Editor.
MUSPRATT (S.) Chemistry, Theoretical, Practical, and Analytical, as applied or relating to the Arts and Manufactures. Vol. I. 4to. *London*, &c.	The Author.
NAPOLI (R.) Sur la Corrélation des Forces Physiques, &c. 8vo. *Naples* 1857.	The Author.
NEISON (F. G. P.) Contributions to Vital Statistics, &c. Third Edition. 4to. *London* 1857.	The Author.
PANDER (C. H.) Monographie der Fossilen Fische des Silurischen Systems der Russisch-Baltischen Gouvernements. 4to. *St. Petersburg* 1856.	L'État-major du Corps des Ingénieurs des Mines de Russie.
——— Ueber die Placodermen des Devonischen Systems. 4to. *St. Petersburg* 1857.	———
PARLATORE (F.) Flora Italiana, ossia Descrizione delle Piante, &c. Vol. II. Parte 2da. 8vo. *Firenze* 1857.	The Author.
PEACOCK (T. B.) On Malformations, &c., of the Human Heart; with Original Cases. 8vo. *London* 1858.	The Author.
PEIRCE (B., For. Mem. R.S.) Physical and Celestial Mechanics. 4to. *Boston* 1855.	The Author.
PELIKAN (E.) Beiträge zur gerichtlichen Medizin, Toxikologie, und Pharmakodynamik. 8vo. *Würzburg* 1858.	The Author.
PLANA (J., For. Mem. R.S.) Mémoire sur un Rapprochement nouveau entre la Théorie moderne de la propagation linéaire du Son, dans un Tuyau cylindrique, &c., et la Théorie des Pulsions, &c. &c. 4to. *Turin* 1857.	The Author.
——— Mémoire sur le Mouvement conique à double Courbure d'une Pendule Simple, &c. 4to. *Turin* 1858. (Extraits des Mém. de l'Acad. Turin.)	———
——— Recherches Historiques sur la première Explication de l'Equation Séculaire du Moyen Mouvement de la Lune, d'après le Principe de la Gravitation Universelle. 4to. *Turin* 1857.	———
PLATEAU (J.) Recherches expérimentales et théoriques sur les Figures d'Équilibre d'une Masse liquide sans Pesanteur. 4me Série. 4to. *Bruxelles* 1857.	The Author, per M. Faraday, Esq., F.R.S.
POEY (A.) Considérations philosophiques sur un Essai de Systématisation subjective des Phénomènes Météorologiques. 8vo. 1857.	The Author.
——— Répartition géographique de l'Universalité des Météores, &c. 8vo. *Paris* 1858.	———
——— Couleurs des Globes filants observés à Paris de 1841 à 1853, &c. 4to. (Extrait des Comptes Rendus, 1857.)	———
PONCELET (J. V., For. Mem. R.S.) Rapport sur les Machines et Outils employés dans les Manufactures, &c. Première Partie relative aux matières non Textiles. Deuxième Partie relative aux matières Textiles. 8vo. *Paris* 1857.	The Author.
PORTLOCK (J. E., F.R.S.) Address delivered at the Anniversary Meeting of the Geological Society of London, on the 20th of February, 1857. 8vo. *London* 1857.	The Author.

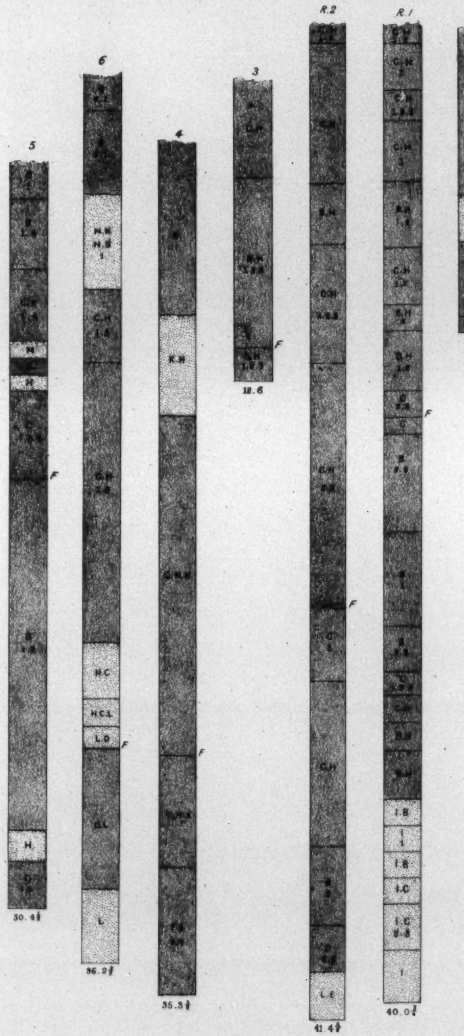
Presents.	Donors.
PORTRAITS:—	
Portrait of the late Lieut. James Holman, R.N., F.R.S.	Andrew Holman, Esq.
Portrait of the late William Clift, Esq., F.R.S.	Prof. Owen, F.R.S.
PRESTWICH (J., F.R.S.) The Ground beneath us: its Geological Phases and Changes, &c. 8vo. *London* 1857.	The Author.
PUSELEY (D.) The Rise and Progress of Australia, Tasmania, and New Zealand, &c. 8vo. *London* 1858.	The Author.
QUETELET (A., For. Mem. R.S.) Observations des Phénomènes Périodiques. 4to. (Extrait du t. xxxi des Mém. Acad. Belgique.)	The Author.
——— Rapport sur un Mémoire de J. F. Rameaux. 8vo. (Extrait des Bulletins)	———
——— Note sur la Composition de l'Atmosphère. 8vo. (Extrait.)	———
——— Occultation de Jupiter par la Lune, le 2 Janvier, 1857. 8vo. (Extrait.)	———
——— Eclipse de Soleil du 15 Mars, 1858. 8vo. (Extrait.)	———
——— Observations des Passages de la Lune et des Étoiles de même Culmination. 8vo. (Extrait.)	———
——— Variations annuelles et horaires des Instruments météorologiques à Bruxelles. 8vo. (Extrait.)	———
——— Communication de M. Lamont sur la Composition de l'Atmosphère. 8vo. (Extrait.)	———
——— Annales de l'Observatoire Royal de Bruxelles. Tome XII. 4to. *Bruxelles* 1857.	The Observatory.
——— Annuaire de l'Observatoire Royal de Bruxelles, 25e année. 12mo. *Bruxelles* 1857.	———
——— Rapport addressé à M. le Ministre de l'Intérieur sur l'État et les Travaux de l'Observatoire Royal pendant l'année 1856. 8vo. *Bruxelles*.	———
REGNAUD (C.) Histoire Naturelle, hygiénique et économique du Cocotier (*Cocos nucifera*, Linn.). 4to. *Paris*.	The Author.
REMY (J.) Ascension du Pichincha. 8vo. *Chalons-sur-Marne* 1858.	The Author.
RENNIE (G., F.R.S.) On the Quantity of Heat developed by Water when violently agitated, &c. 8vo. *London* 1857.	The Author.
——— On the Employment of Rubble Béton, or Concrete, in Works of Engineering and Architecture. 8vo. *London* 1858. (Excerpt Minutes of Proc. Inst. C. E.)	———
RESLHUBER (P. A.) Magnetische Beobachtungen zu Kremsmünster in den Jahren 1851-53. 4to. *Wien* 1856.	The Author.
——— ——— im Jahre 1854. 4to. *Wien* 1857.	———
——— Bericht über die Kometen von den Jahren 975, 1264 und 1556. 8vo. *Kremsmünster* 1857.	———
——— Beiträge zur Klimatologie von Oberösterreich. 8vo. *Linz* 1855.	———
——— Resultate aus den im Jahre 1856 auf der Sternwarte zu Kremsmünster angestellten meteorologischen Beobachtungen. 8vo. *Linz* 1857.	———

Presents.	Donors.
RESLHUBER (P. A.) Untersuchungen über das Atmosphärische Ozon. 8vo. *Wien.* (Excerpt: Sitzungsberichte.)	The Author.
——— Ueber Prof. Stampfer's Lichtpunkt-Mikrometer im Fernrohre des Meridiankreises der Sternwarte zu Kremsmünster. 8vo. *Wien.* (Excerpt: Sitzungsberichte.)	———
——— Ueber den Ozongehalt der Atmosphärischen Luft. 8vo. *Wien.* (Excerpt: Sitzungsberichte.)	———
RICO Y SINOBAS (M.) Observaciones actinométricas verificadas en Madrid con Motivo del Eclipse de Sol de Marzo 1858. 4to. *Madrid* 1858.	The University of Madrid.
RITTER (C., For. Mem. R.S.) Die Erdkunde von Asien. Bd. IX. Theil 1. Klein Asien. 8vo. *Berlin* 1858.	The Author.
ROBINSON (G.) Contributions to the Physiology and Pathology of the Circulation of the Blood. 8vo. *London* 1857.	The Author.
RONDOT (N.) Notice du Vert de Chine et de la Teinture en Vert chez les Chinois. 8vo. *Paris* 1858.	The Author, per Warren De la Rue, Esq., F.R.S.
SANDEMAN (P.) Monthly Tables of daily Means of Meteorological Elements, deduced from Observations taken at Georgetown, Demerara, during eleven Years commencing Jan. 1846. 4to. *Greenock* 1857.	The Government of British Guiana.
SAUMAREZ (Rear-Admiral). An Introductory Key to the Hieroglyphic Phraseology of the Old Testament, &c. 4to. *Bath.*	Rear-Admiral W. H. Smyth, F.R.S.
SAVINI (S.) Storia degli Scandagli Marittimi, &c. 8vo. *Torini* 1858.	The Author.
SECCHI (A., For. Mem. R.S.) Descrizione del Nuovo Osservatorio del Collegio Romano, &c. 4to. *Roma* 1856.	The Author.
SELLA (Quintino). Sulle Forme cristalline di alcuni Sali di Platino e del Boro Adamantino. 4to. *Torino* 1857.	The Author.
——— Sulle Forme cristalline del Boro Adamantino. (Seconda Memoria.) 4to. *Torino* 1857.	———
SLOMAN (H.) Leibnitzens Anspruch auf die Erfindung der Differenzial Rechnung. 4to. *Leipzig* 1857.	The Author.
SMYTH (C. P., F.R.S.) Astronomical Observations made at the Royal Observatory, Edinburgh. Vol. XI. for 1849-54.	The Observatory.
SOPWITH (T., F.R.S.) Notes of a Visit to Egypt, by Paris, Lyons, Nismes, Marseilles, and Toulon. 12mo. *London* 1857. (Printed for Private Circulation.)	The Author.
STAINTON (H. T.) The Natural History of the Tineina. Vol. II. containing Lithocolletis, Part 1 (assisted by Professor Zeller and J. W. Douglas). 8vo. *London* 1857.	The Author.
STARK (J.) Address to the Meteorological Society of Scotland. 8vo. *Edinburgh* 1858.	The Author.
STOKES (G. G.) On the Discontinuity of Arbitrary Constants which appear in Divergent Developments. 4to. *Cambridge* 1858. (From Trans. Cam. Phil. Soc.)	The Author.
STUDIATI (S.) Déscription des Fossiles de la Brèche Osseuse de Monreale de Bonaria près de Cagliari. 8vo. *Turin* 1857.	The Author.
SYKES (W. H., F.R.S.) Speech of Colonel Sykes in the House of Commons, on Thursday, Feb. 18, 1858, on the proposed India Bill. 8vo. *London* 1858.	The Author.
THOMÉ DE GAMOND (A.) Étude pour l'avant-Projet d'un Tunnel sous-Marin entre l'Angleterre et la France, &c. 4to. *Paris* 1857.	The Author.

Presents.	Donors.
VILLARCEAU YVON (A. J.) Détermination des Orbites des Planètes et des Comètes. (Extrait des Annales de l'Observatoire Impérial de Paris. Tome III.) 4to. *Paris* 1857.	The Author.
VILLE (G.) Cours de Physique Végétale. 4to. *Paris* 1857. Séance d'Ouverture. (Extrait.)	The Author.
WARNER (J.) Studies in Organic Morphology. 8vo. *Philadelphia* 1857.	The Author.
WHITE (Walter). A July Holiday in Saxony, Bohemia, and Silesia. 8vo. *London* 1857.	The Author.
WILLIAMS (C. G.) A Handbook of Chemical Manipulation. 8vo. *London* 1857.	The Author.
WILSON (E., F.R.S.) A Three Weeks' Scamper through the Spas of Germany and Belgium, with an Appendix on the Nature and Uses of Mineral Waters. 8vo. *London* 1858.	The Author.
WILSON (Rev. J., F.R.S.) Notes on the Constituent Elements, the Diffusion, and the Application of the Maráthí Language. 4to.	The Author.
WROTTESLEY (The Lord, V.P.R.S.) An Address delivered at the first Annual Meeting of the Members and Friends of the Working Men's College, Wolverhampton. 8vo. *Wolverhampton* 1858.	The Author.
YATES (J., F.R.S.) Der Pfahl-Graben. Kurze Allgemeine Beschreibung des Limes Rhæticus und Limes Transrhenanus des Römischen Reiches. 8vo. *Augsburg* 1858.	The Author.

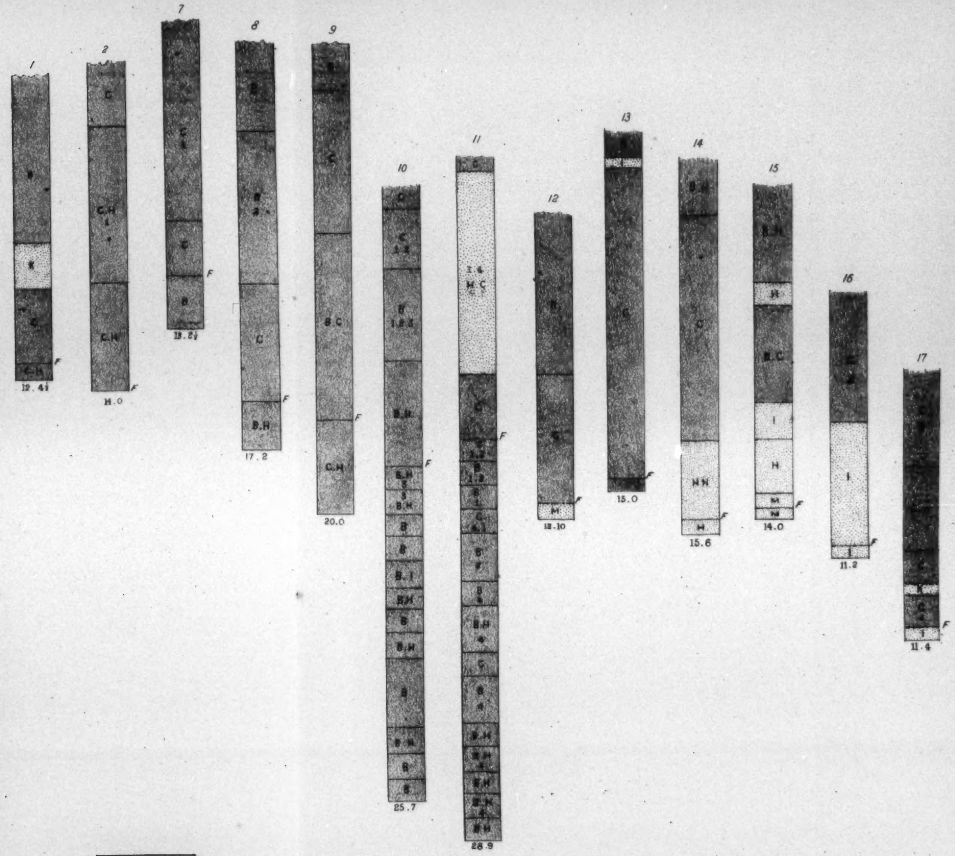


J. Basire lith.


5
6
4
3
R.2
R.1
30.4
36.2
35.3
12.6
41.4
40.0

PITS SUNK IN THE AREA OF MEMPHIS.

INUNDATION LEVEL OF 1851.



Argillaceous earthy sediment more or less mixed with sand. A to G.

Quartzose Sands H to O.

Nº 1. Fragments of Limestone.

2. Fragments of burnt brick.

3. Fragments of Pottery.

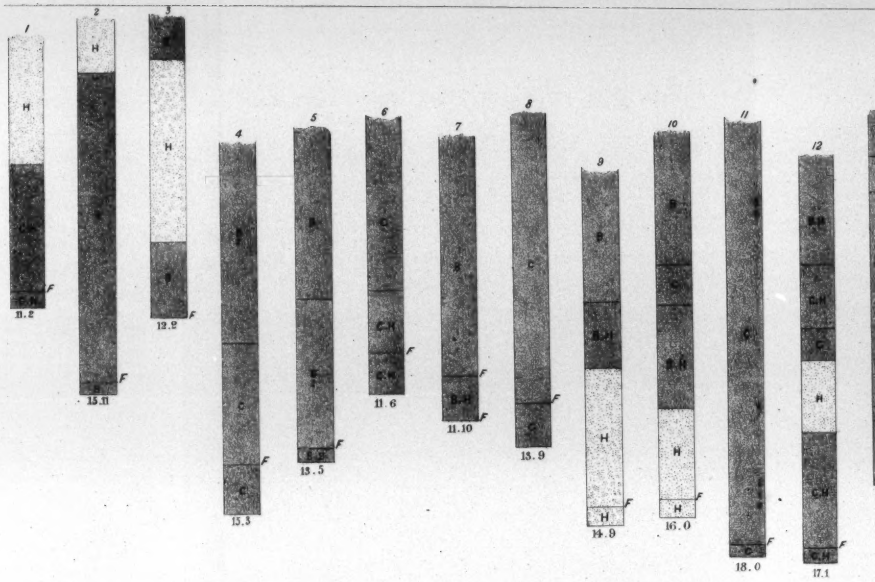
4. Rubbish of buildings with lime mortar.

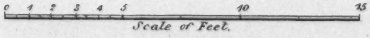
1 2 3 4 5 10 15

Scale of Feet

J. Basire Lith.

PITS SUNK ACROSS THE NILE VALLEY, BETWEEN THE
INUNDATION LE

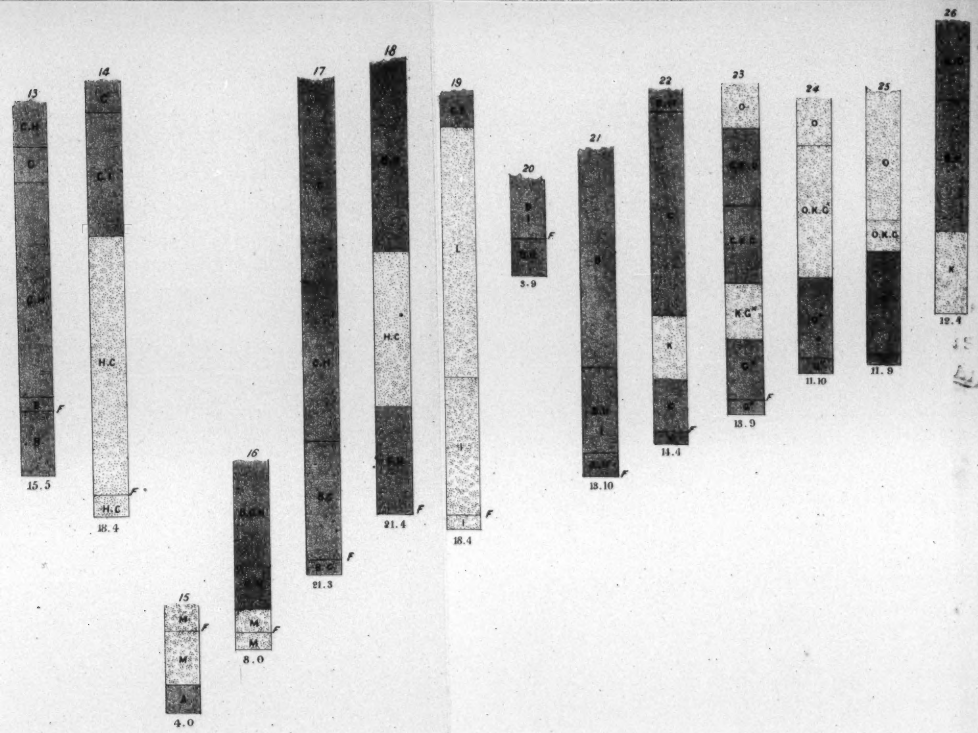




Argillaceous earthy sediment
more or less mixed with sand
A to G.

Quartzose Sands.
H to O.

E LIBYAN AND ARABIAN HILLS, PARALLEL OF MEMPHIS.
LEVEL OF 1851.

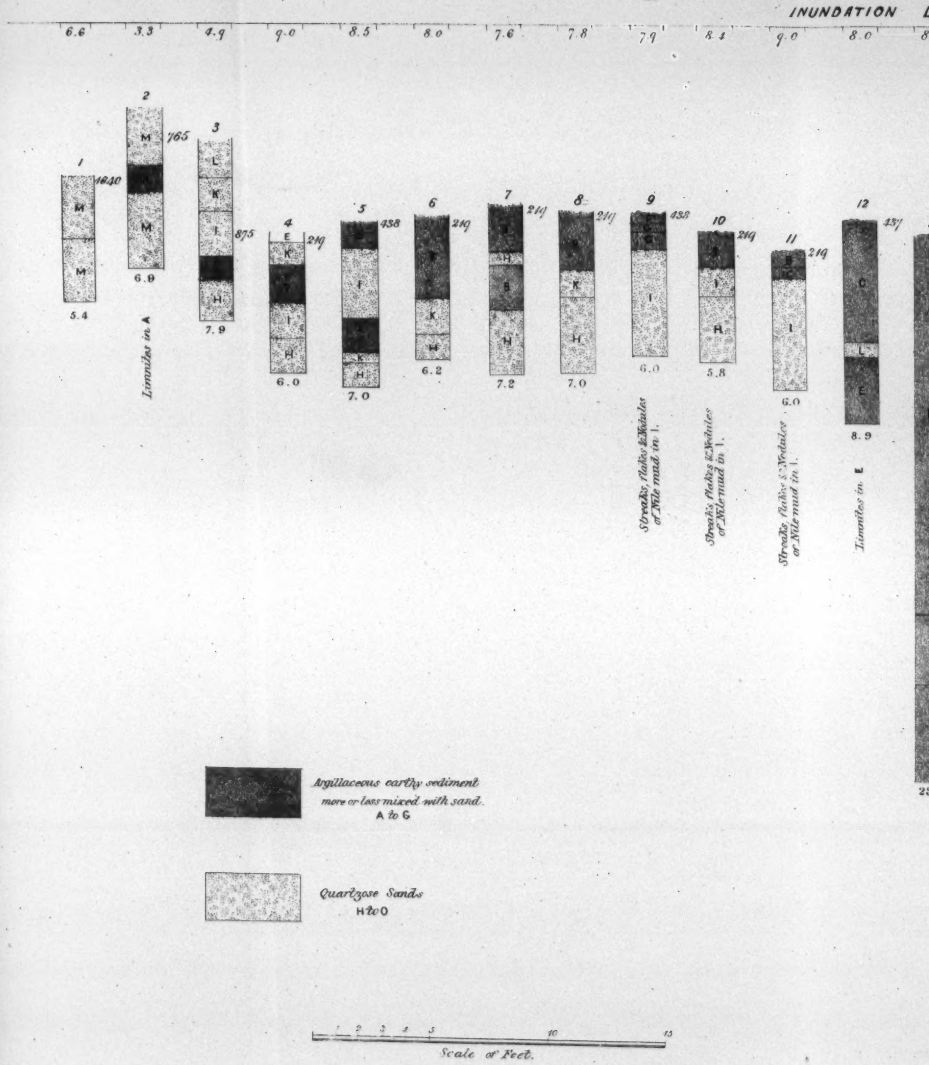


inent.
sand.

Nº 1. Fragments of Limestone.
Nº 2. Fragments of burnt brick.

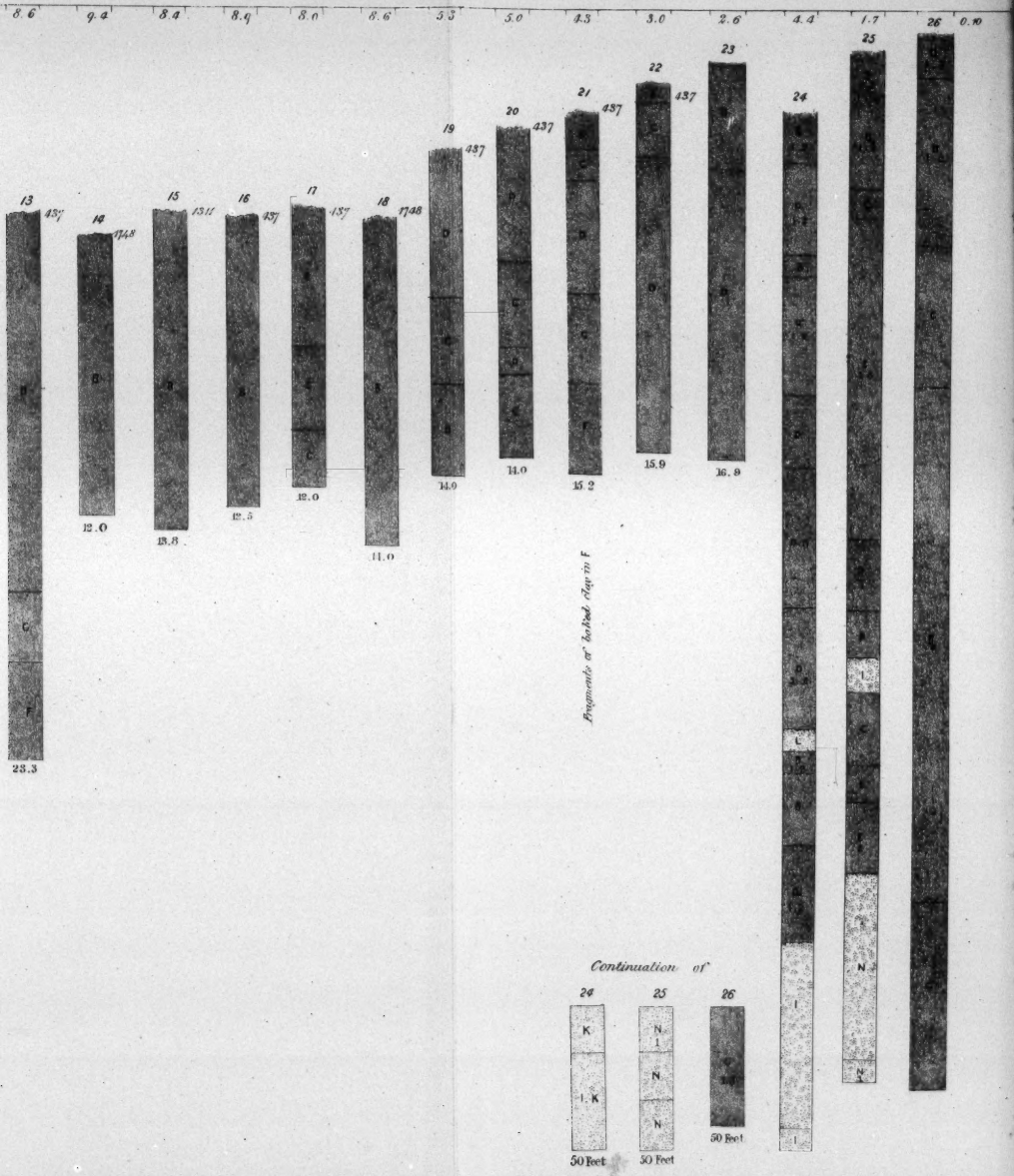
J. Basire lith.

BORINGS BETWEEN THE LIBYAN HILLS AND THE INUNDATION L

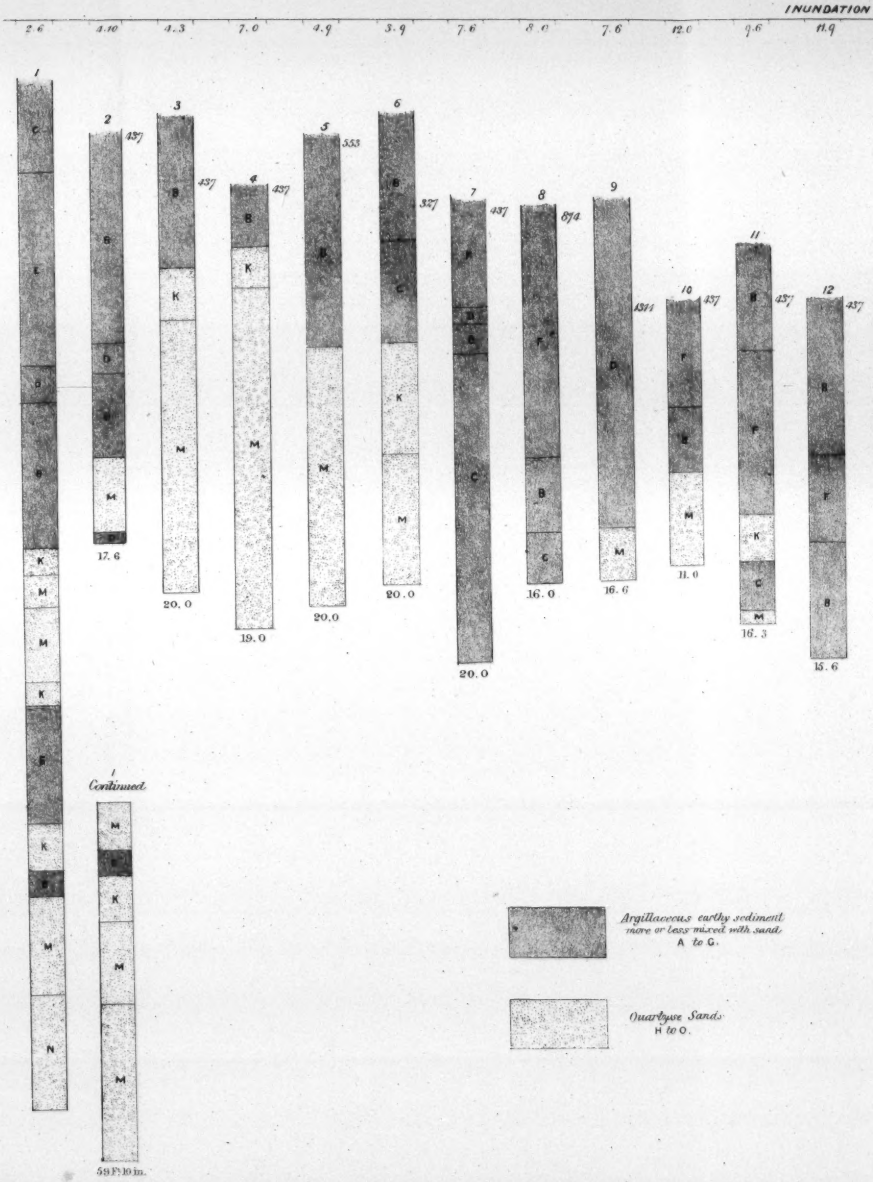


J. Basire, lith.

HE LEFT BANK OF THE NILE, PARALLEL OF HELIOPOLIS.
LEVEL OF 1853.

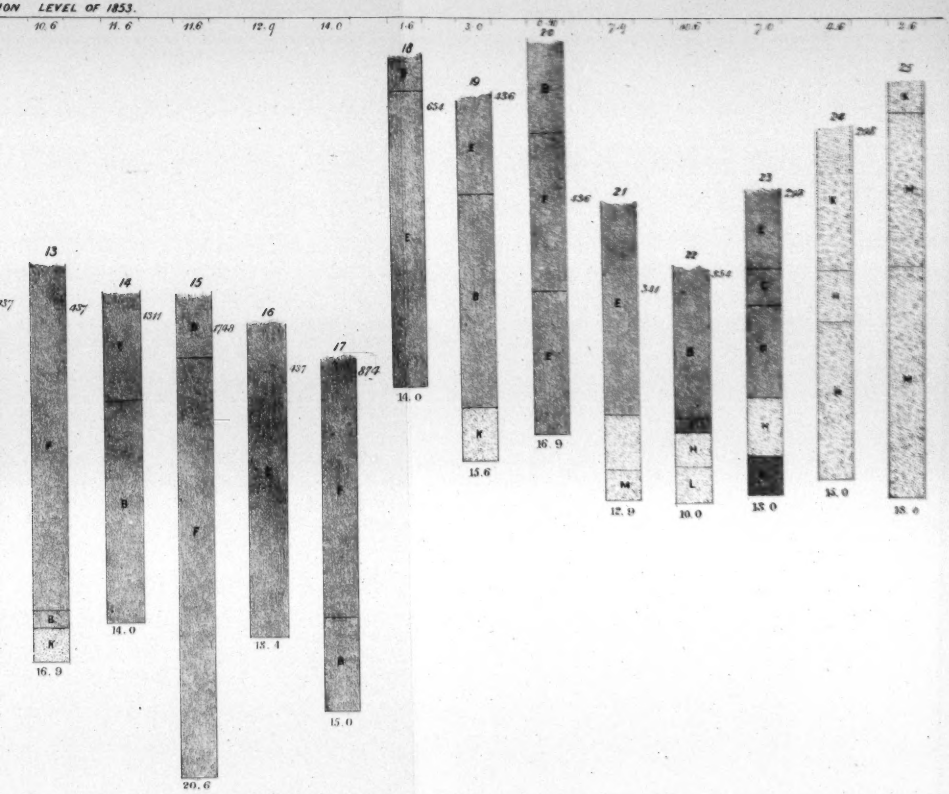


BORINGS BETWEEN THE RIGHT BANK OF THE NILE

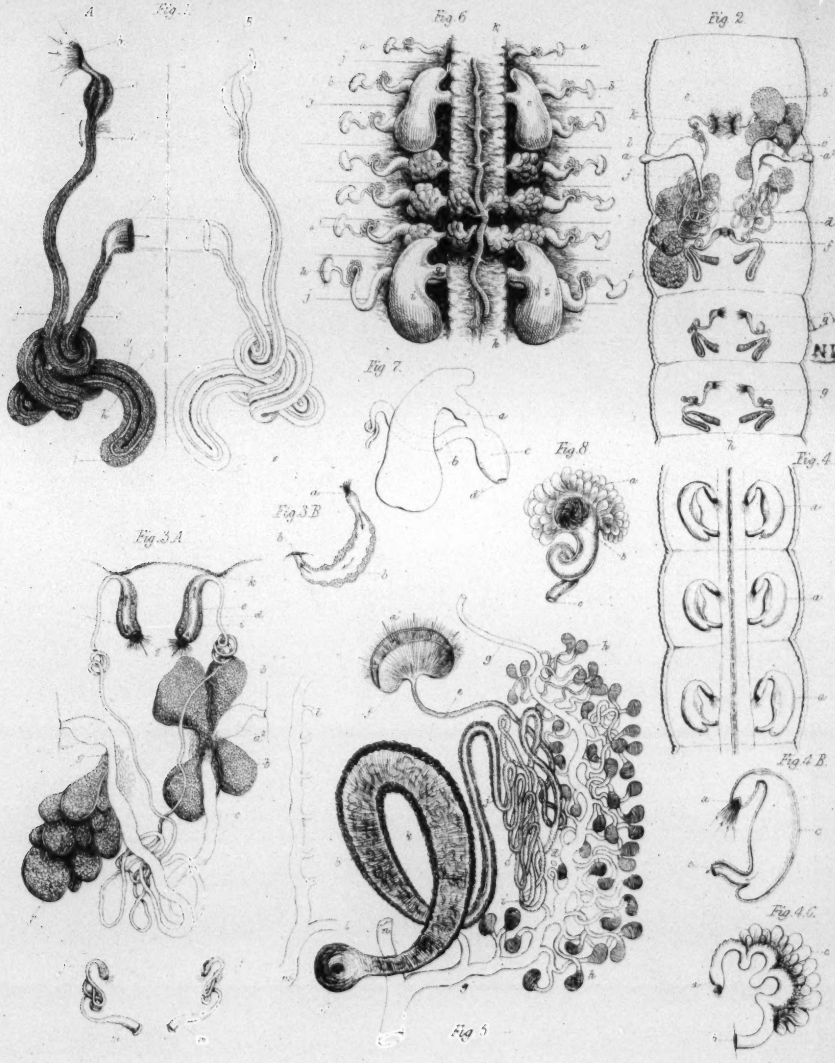


AND THE ARABIAN HILLS. PARALLEL OF HELIOPOLIS.

ON LEVEL OF 1853.



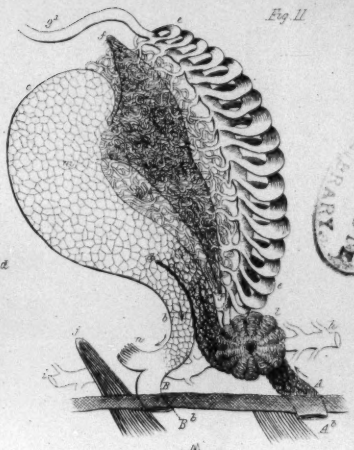
Scale of Feet



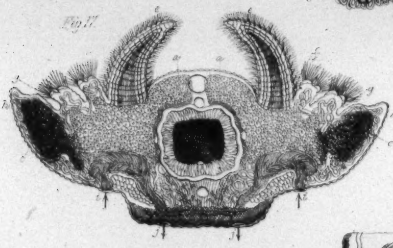
FRANKLIN INSTITUTE

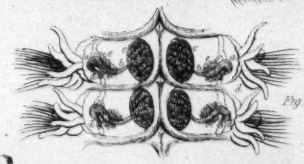
T. Williams del. et sc.

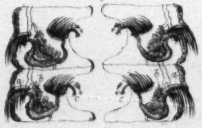
S. Williams del.

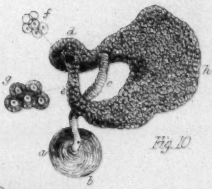


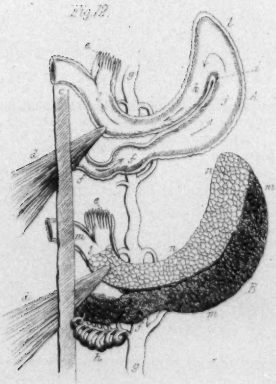
FRANKLIN INSTITUTE LIBRARY

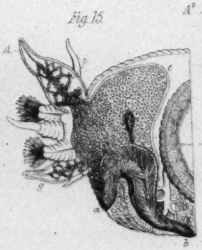


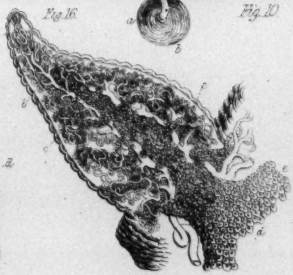






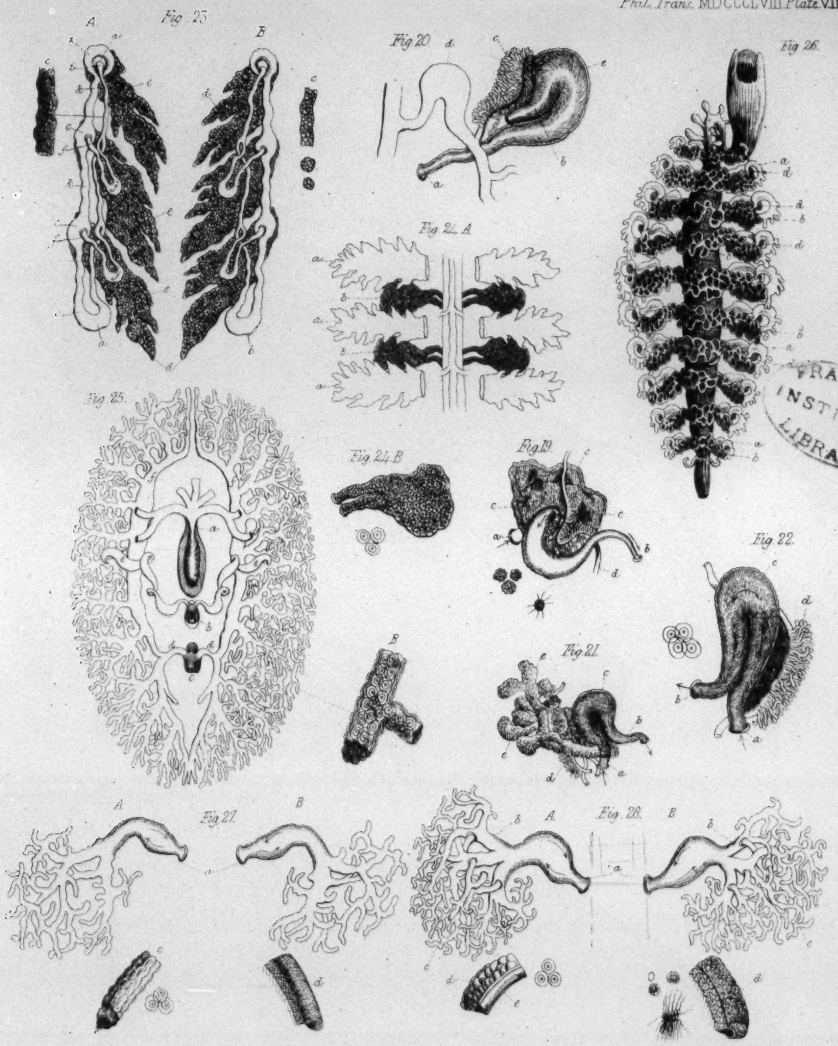






T. Williams, M.D. del.

T. Williams, sc.



FRANKLIN INSTITUTE LIBRARY.

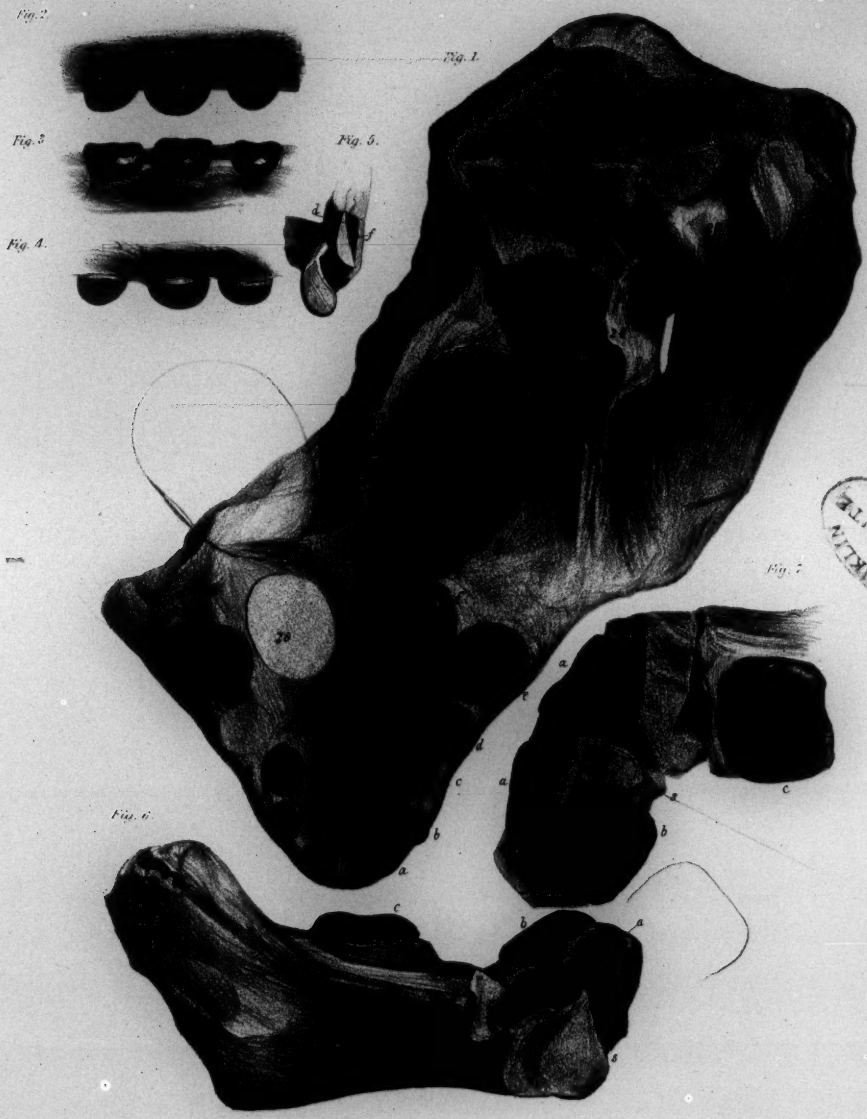
F. Williams, M.D. del.

F. Williams.

FRANKLIN INSTITUTE LIBRARY.

From Nature on Stone by T. Boelcken.

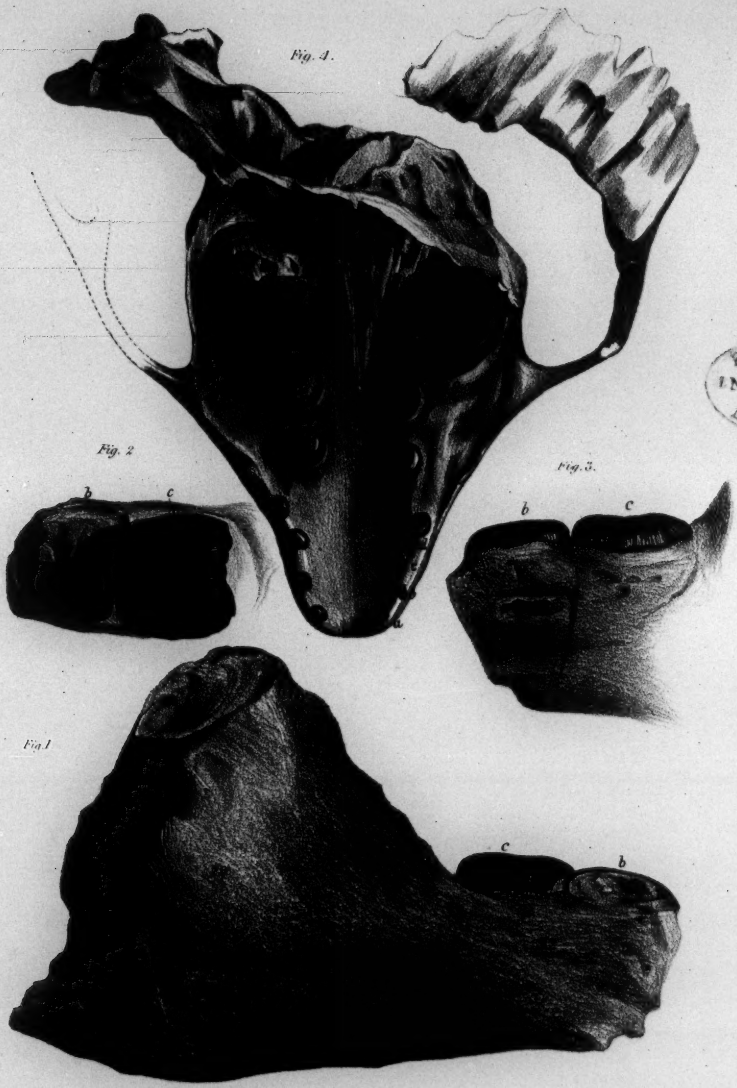
Printed by J. Basire



FRANKLIN INSTITUTE LIBRARY

From Nature on Stone by T. Erxleben.

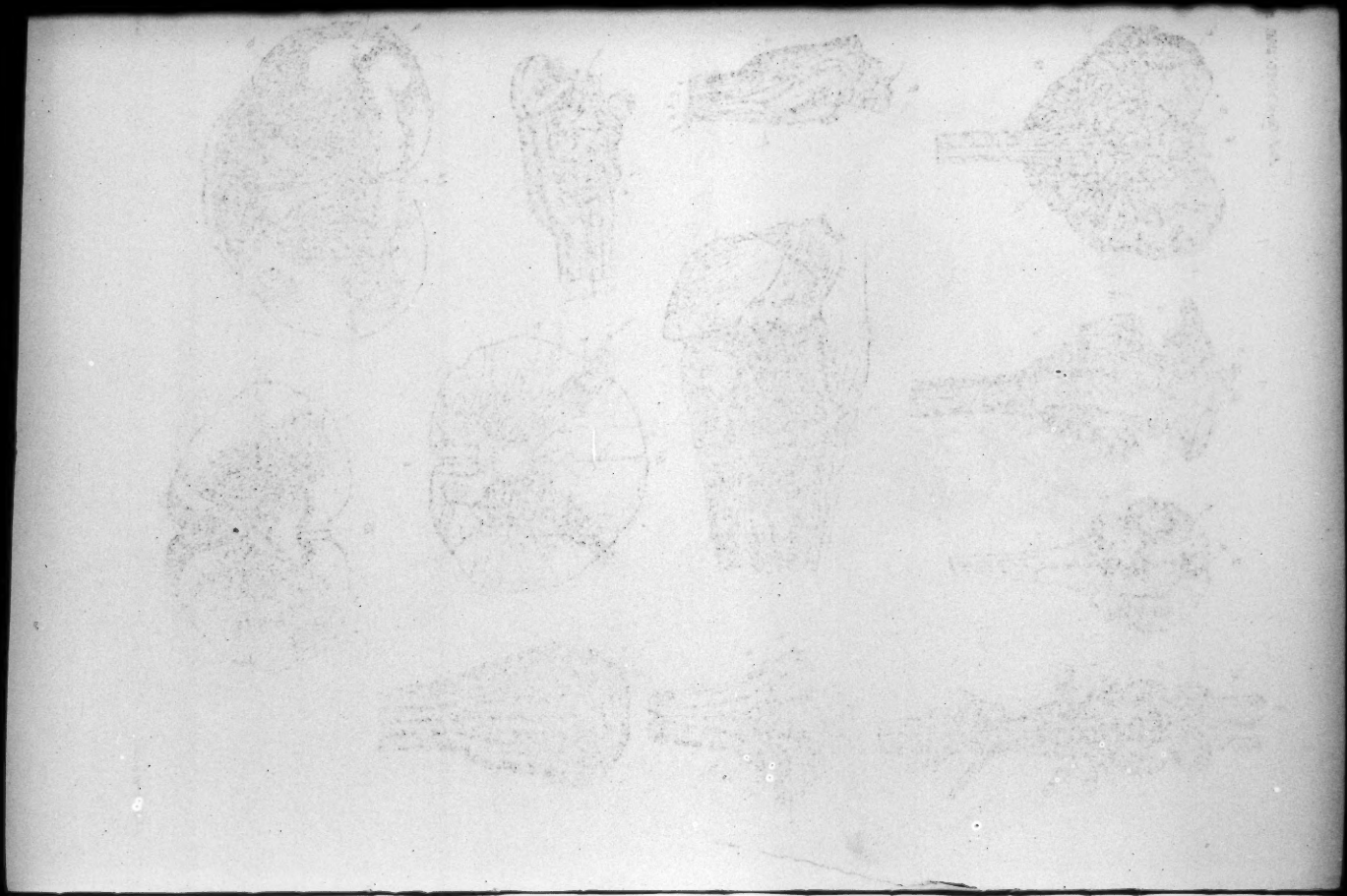
Printed by J. Basire

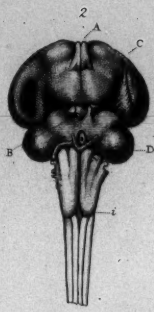


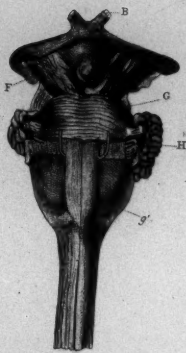
FRANKLIN INSTITUTE LIBRARY.

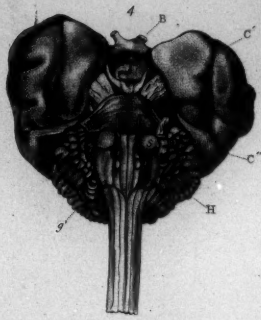
From Nature on Stone by T. Bayfield.

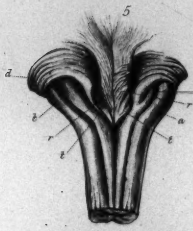
Printed by J. Basire.

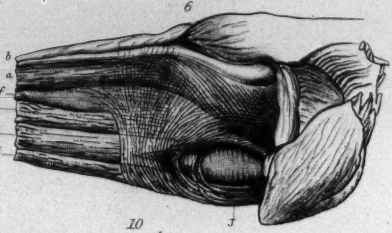


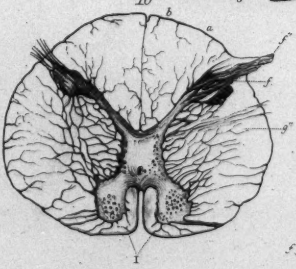


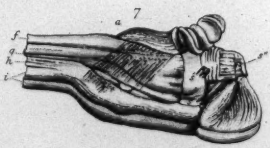


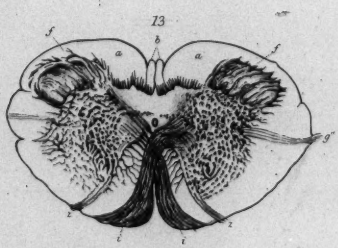


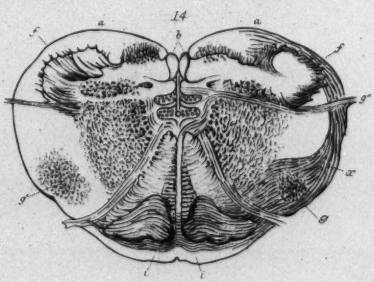








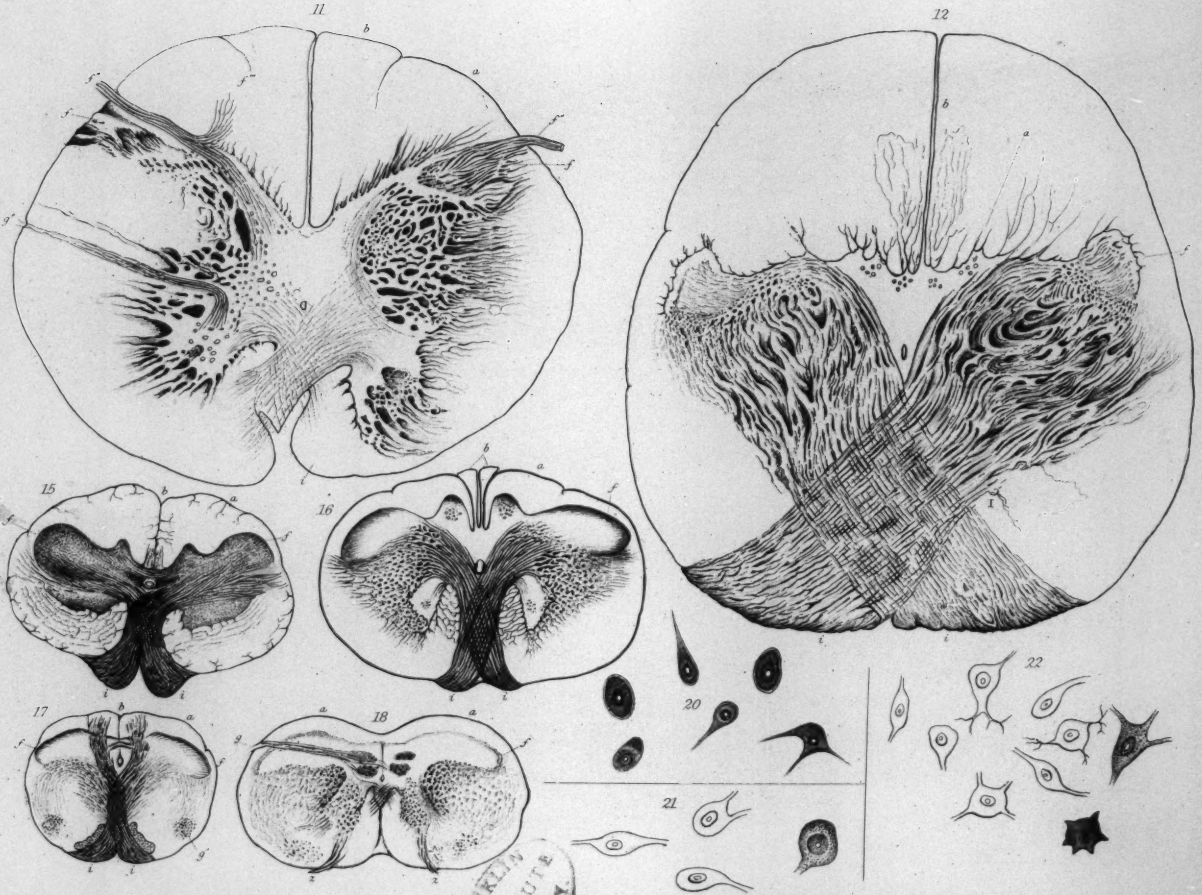




FRANKLIN INSTITUTE LIBRARY

J. L. Clarke del. ad nat.

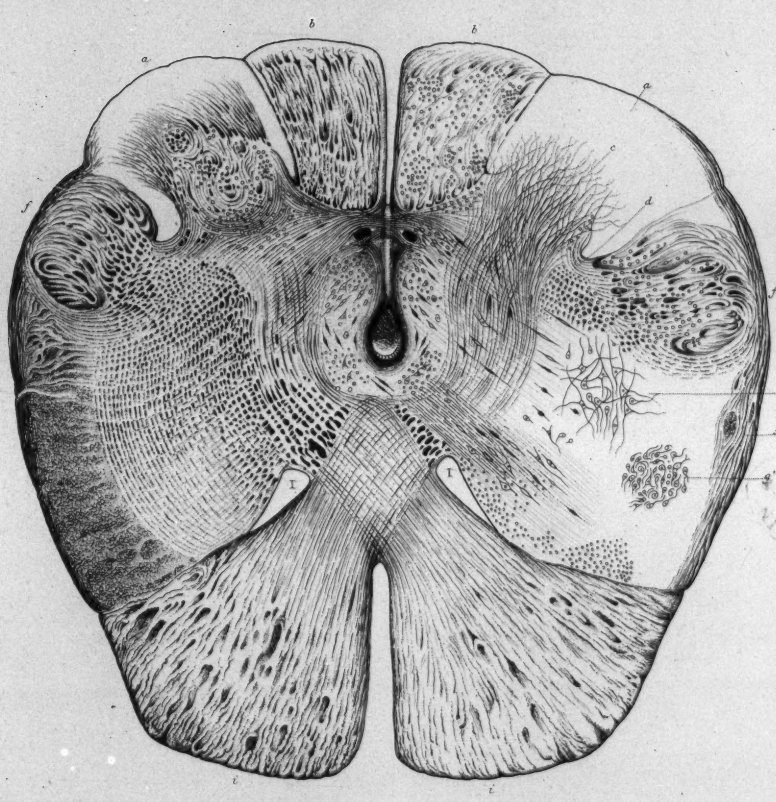
J. Basire sc.



J. L. Clarke, del. ad nat.

J. Basire, sc.

FRANKLIN INSTITUTE LIBRARY

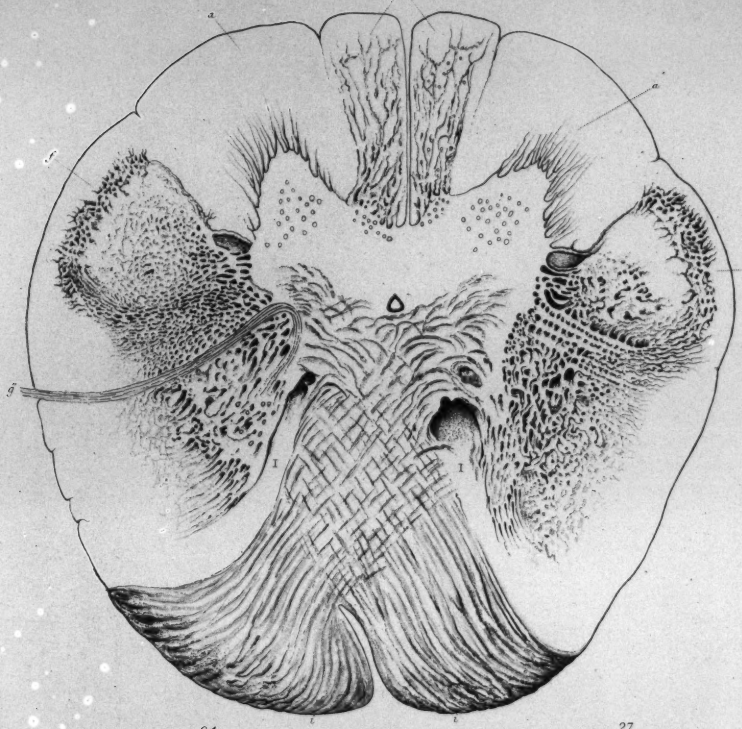


FRANKLIN INSTITUTE LIBRARY

J. L. Clarke del. ad nat.

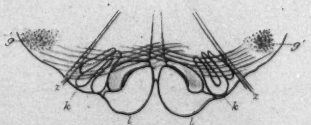
J. Basire sc.

19

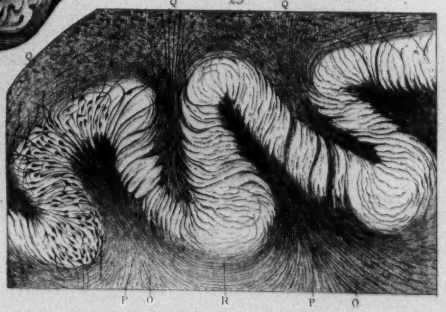


24

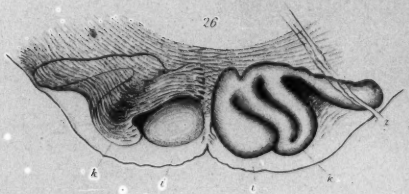
27



25



26

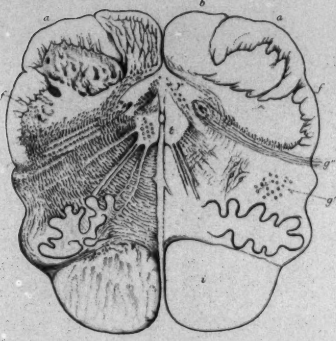


J. L. Clarke, del. ad nat.

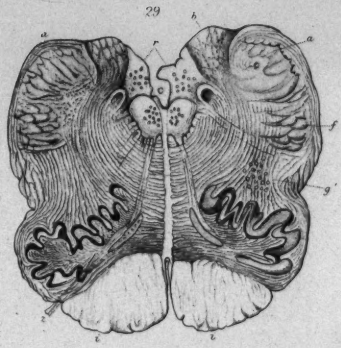
J. Basire, sc.

FRANKLIN INSTITUTE LIBRARY

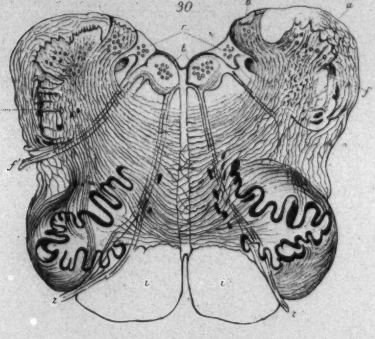
28



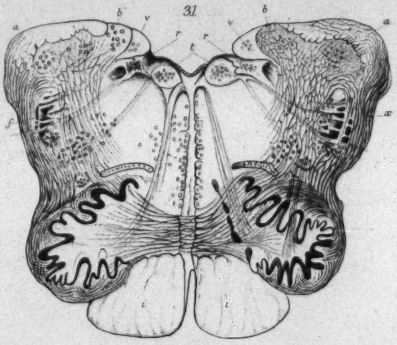
29



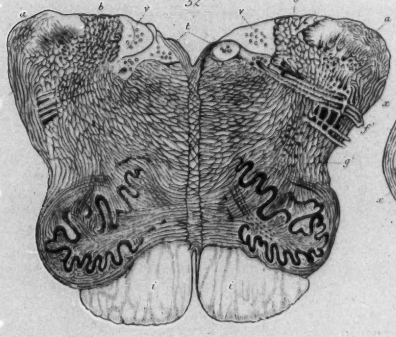
30



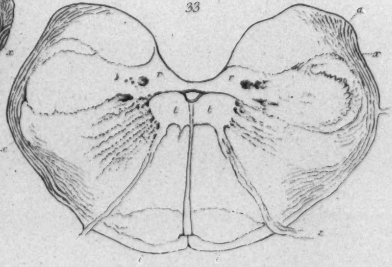
31



32



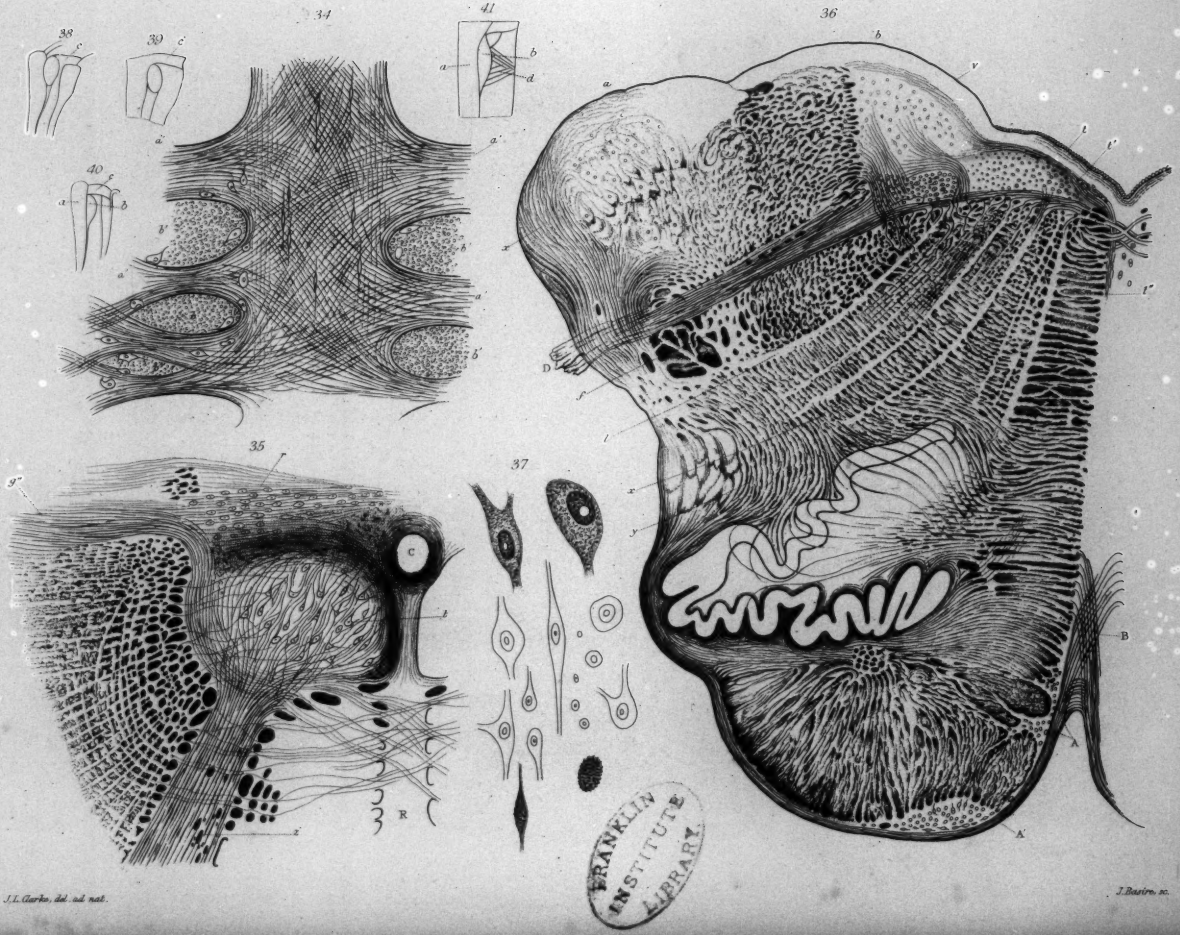
33



FRANKLIN INSTITUTE LIBRARY

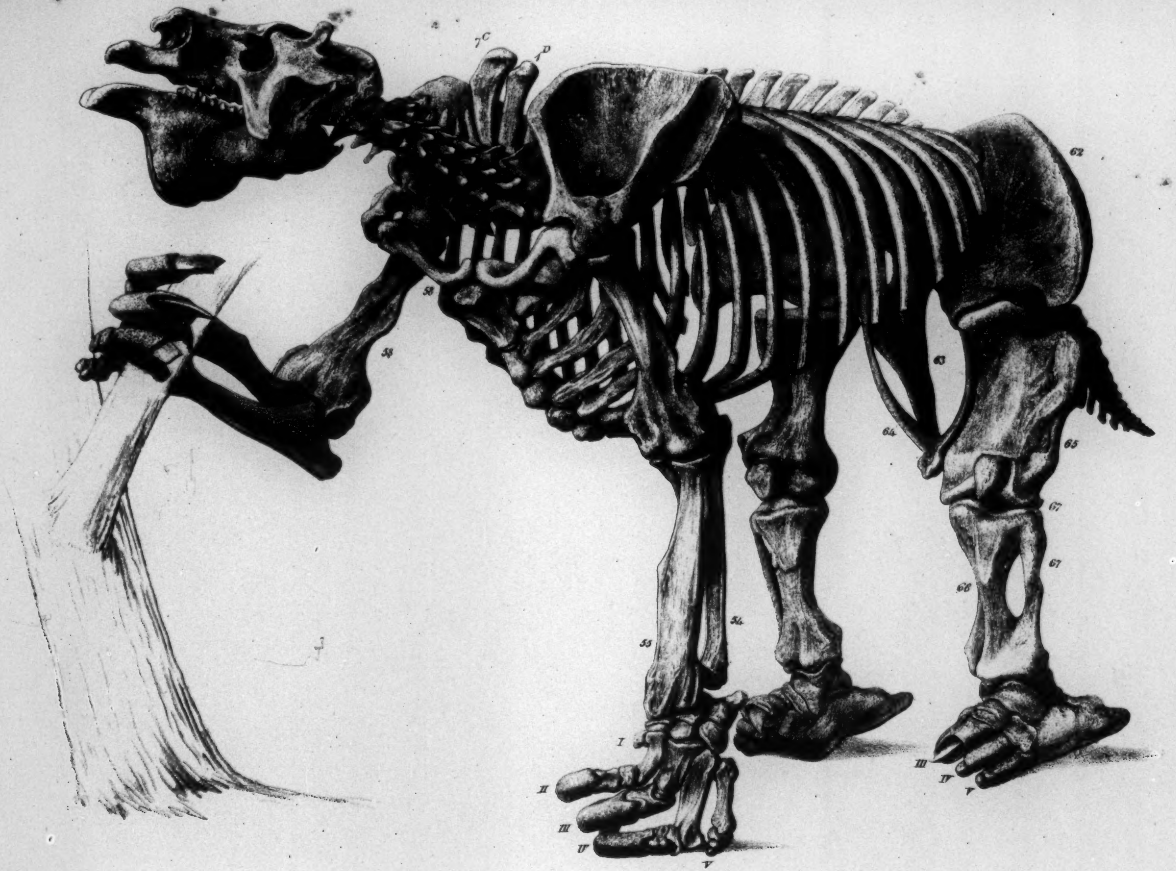
J. L. Clarke del. et lith.

J. Basire sc.



J. L. Clarke, del. ad nat.

J. Basire, sc.



Pinkel. del.t

Printed by J. Basire.

Fig. 1.

Fig. 2.

J. Dinkel, del.

Printed by J. Basire.

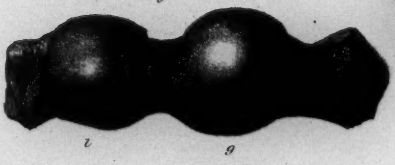
Fig. 2.

Fig. 1.

Fig. 4.

Fig. 3.

Fig. 5.



FRANKLIN INSTITUTE LIBRARY

Jos. Dinkel Lith.

Printed by J. Basire.

Fig. 2.

Fig. 1.

Fig. 5.

Fig. 4.

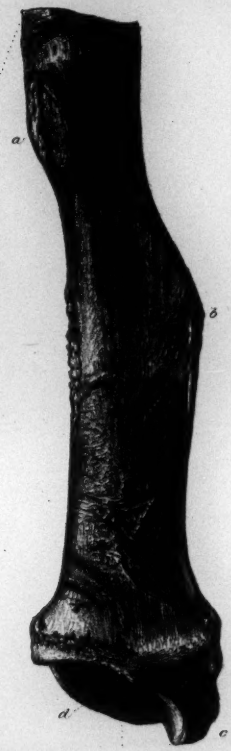


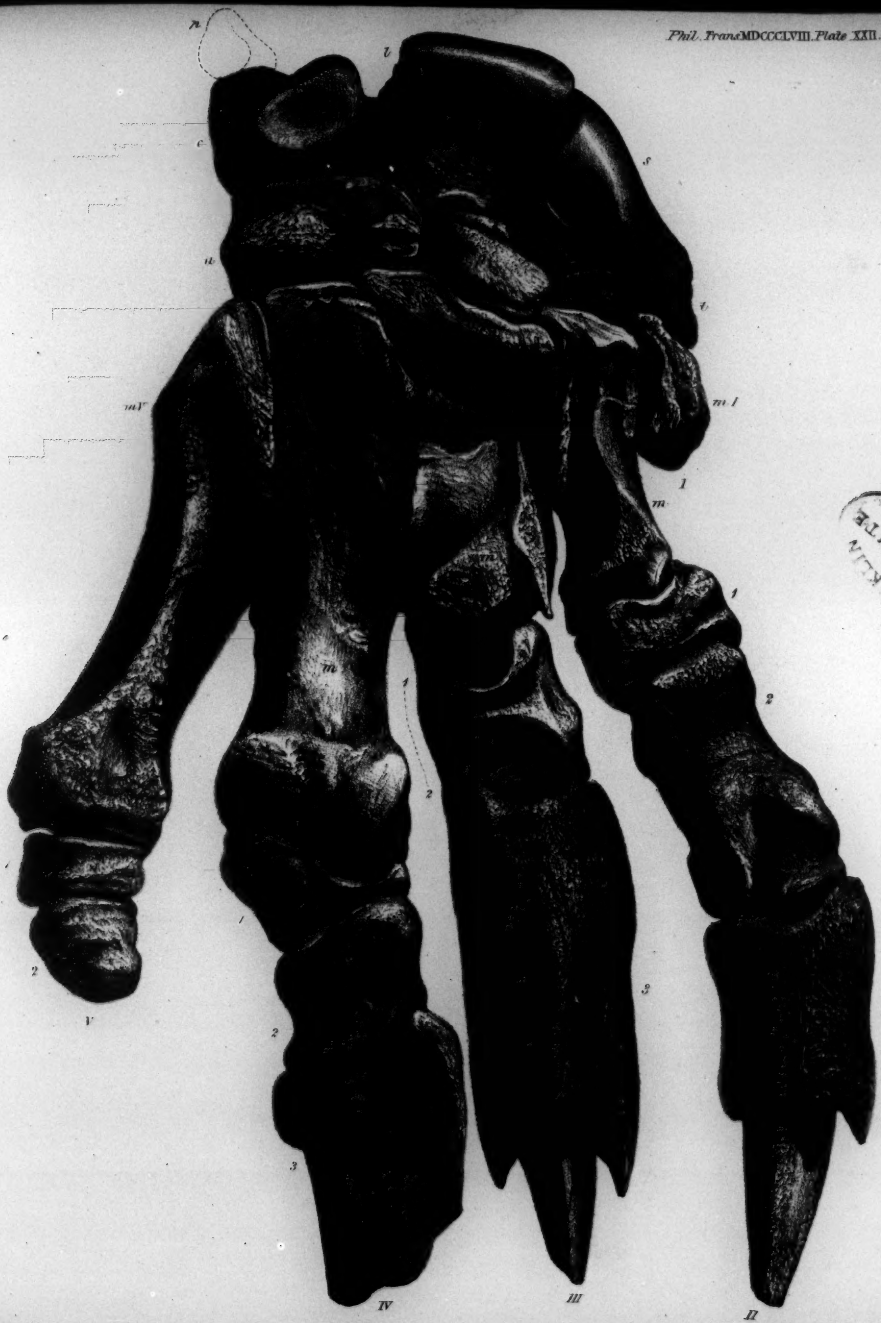
Fig. 3.

Fig. 6.

FRANKLIN INSTITUTE LIBRARY

Sw. Dinkel Lith.

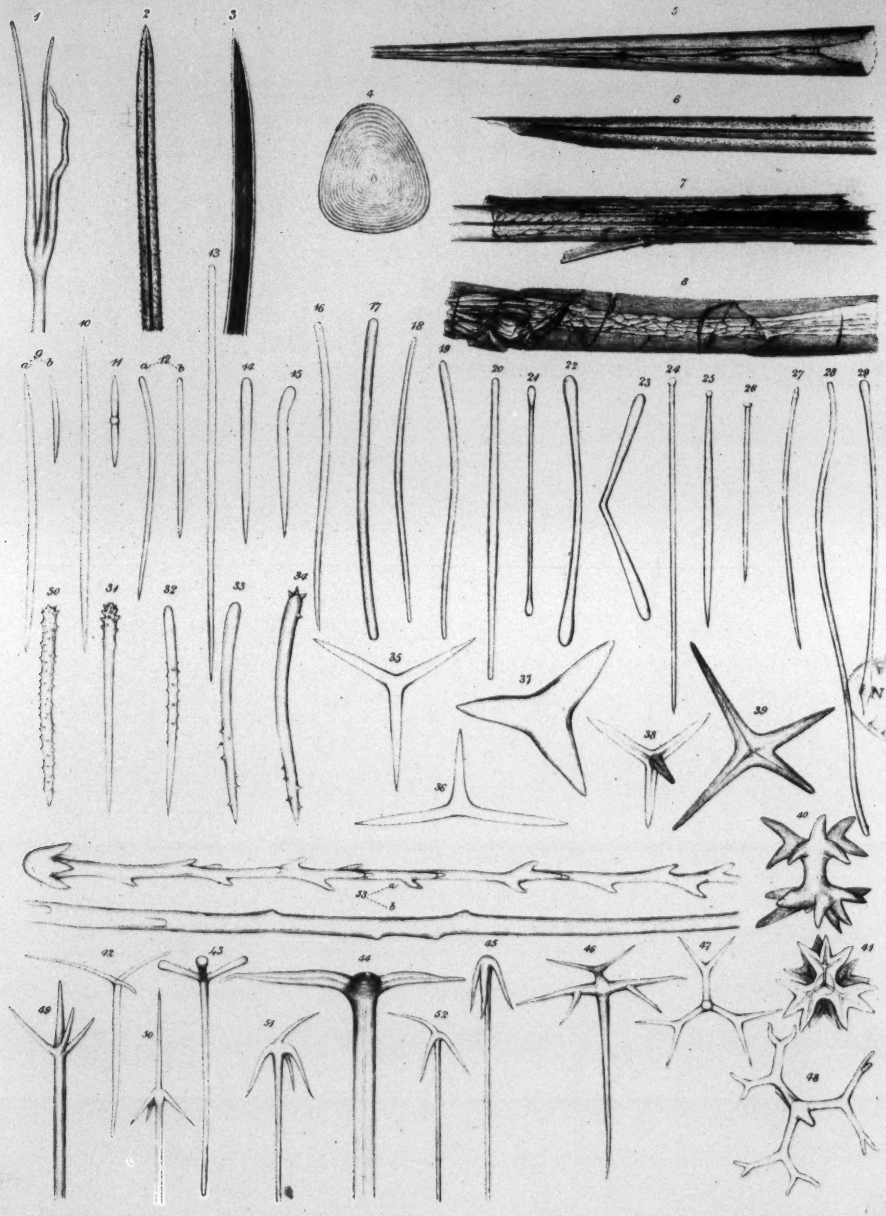
Printed by J. Basire.



FRANKLIN INSTITUTE LIBRARY

J. Dickel, del.

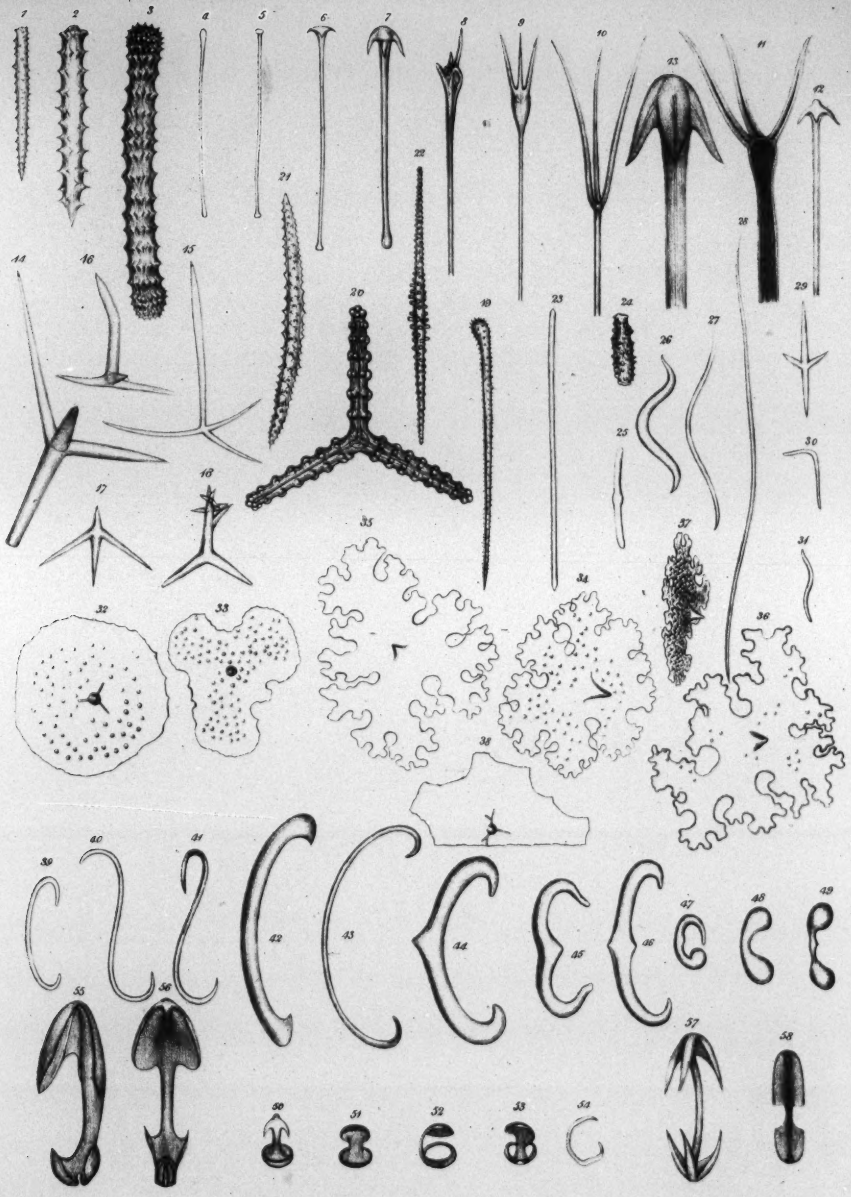
Printed by J. Basire.



FRANKLIN INSTITUTE LIBRARY

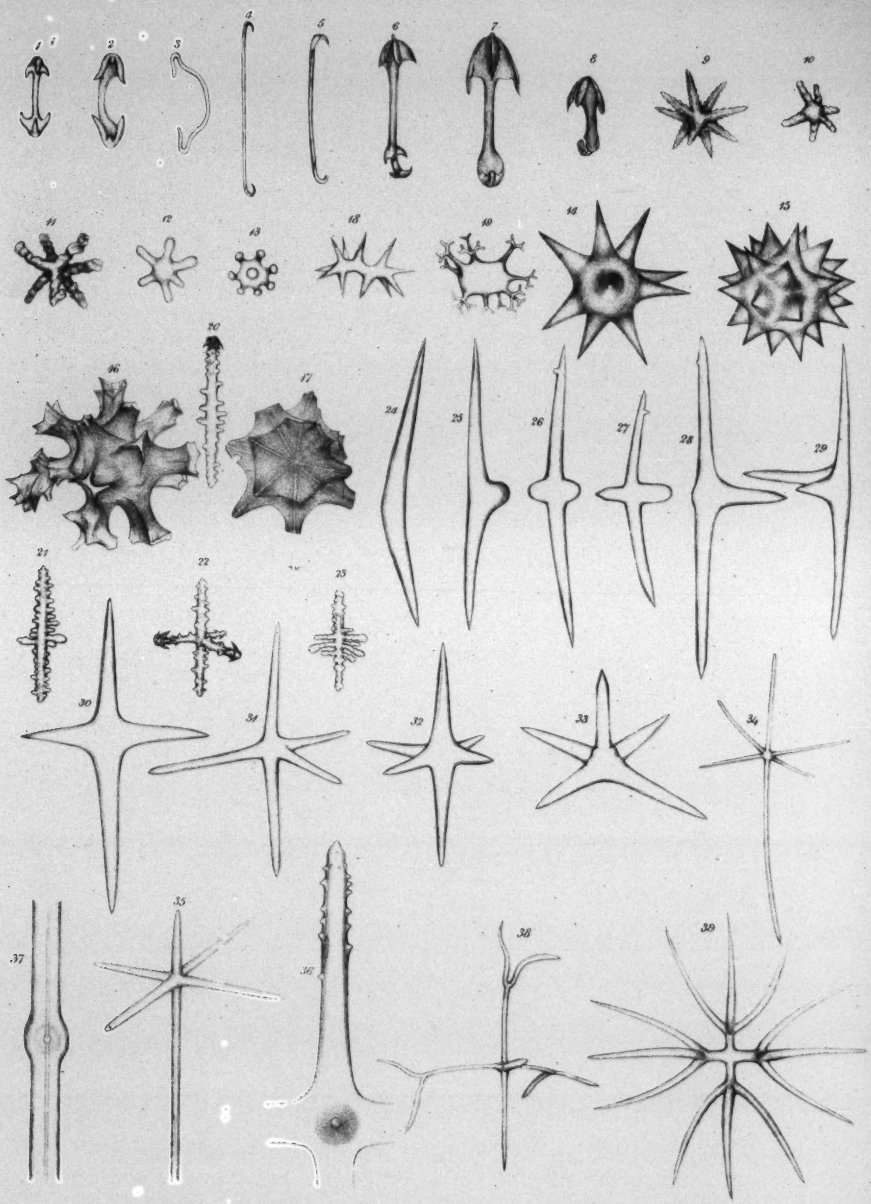
Louis Aldous Lith.

Printed by J. Basire.



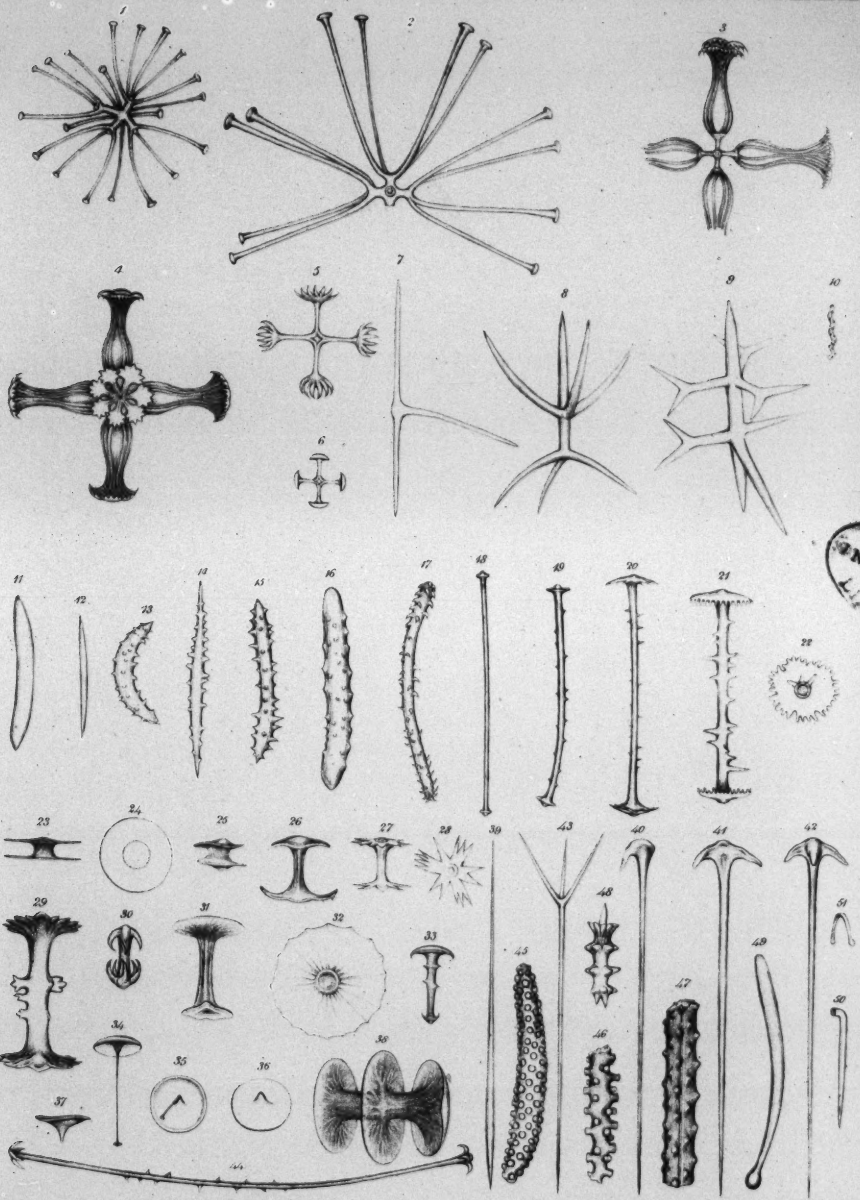
Lowe Aldrus, Delt.

Printed by J. Basire.



Lew. Aldous Lith.

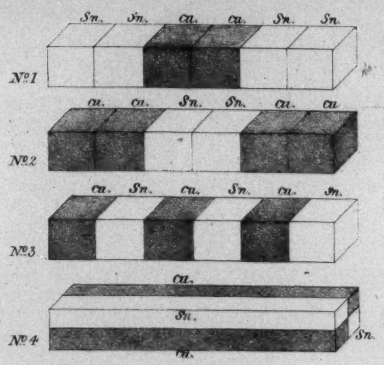
Printed by J. Basire

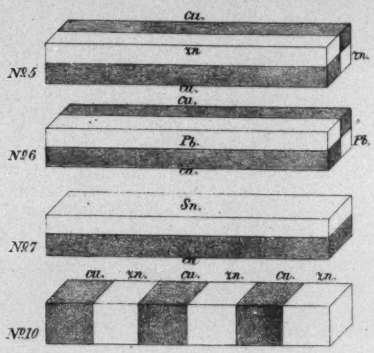


FRANK INSTITU LIBRARY

Geo. Aldous lith.

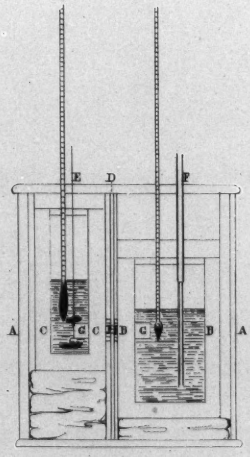
Printed by J. Barre



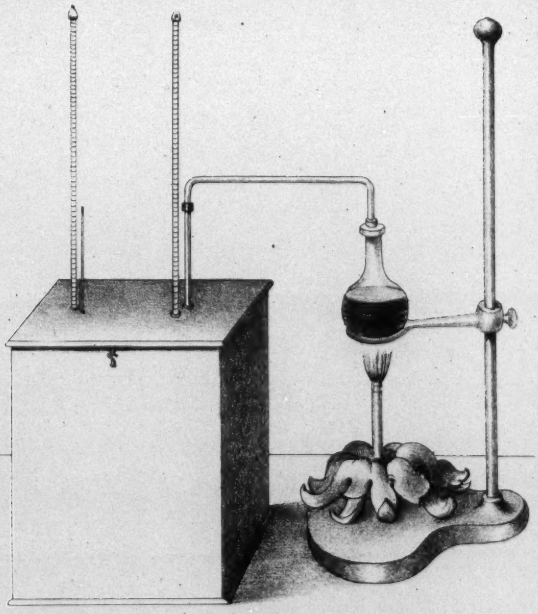


Section of Zinc bar cast vertically — Section of Zinc bar cast horizontally

see page 355.



see pages 350 & 351

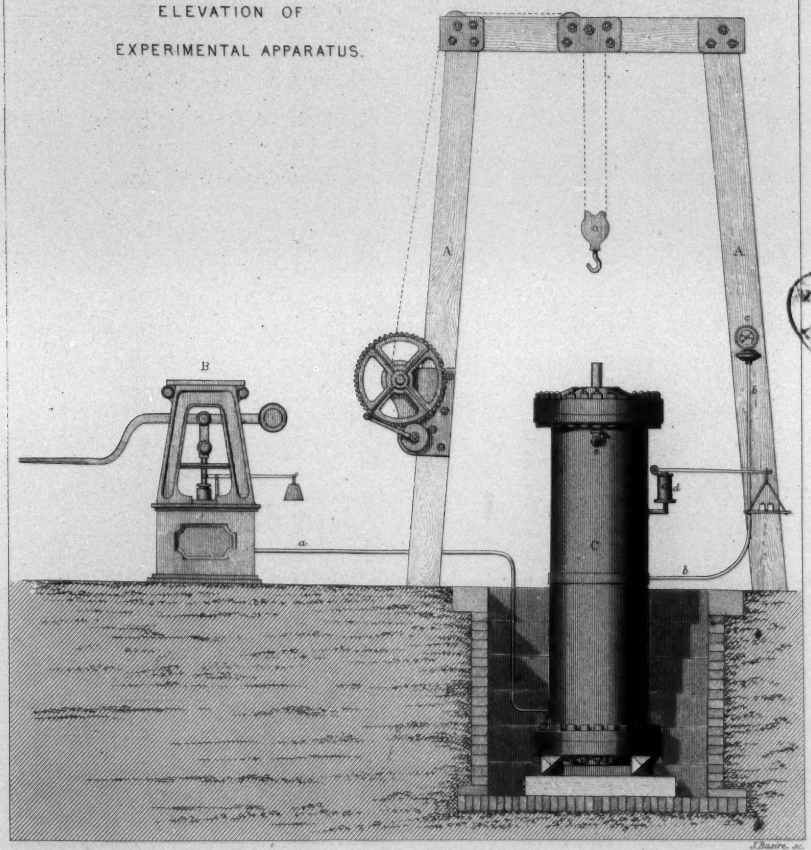


J. Basire lith.

FIG. 1.

ELEVATION OF

EXPERIMENTAL APPARATUS.



J. Basire sc.

FRANKLIN INSTITUTE LIBRARY

FIG. 1.

FIG. 2.

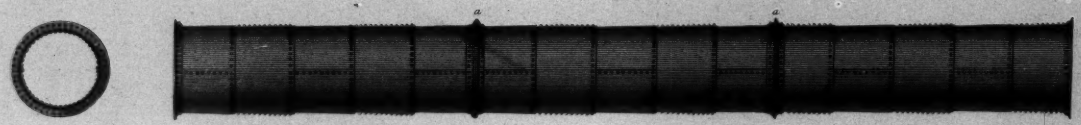
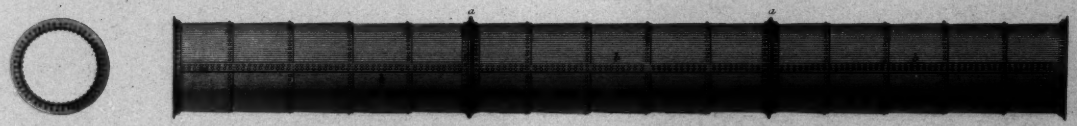
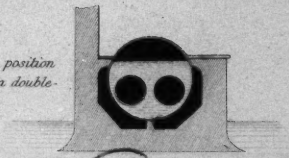


FIG. 3.





Sketch, shewing the position of the flues, in a double-flued Boiler.

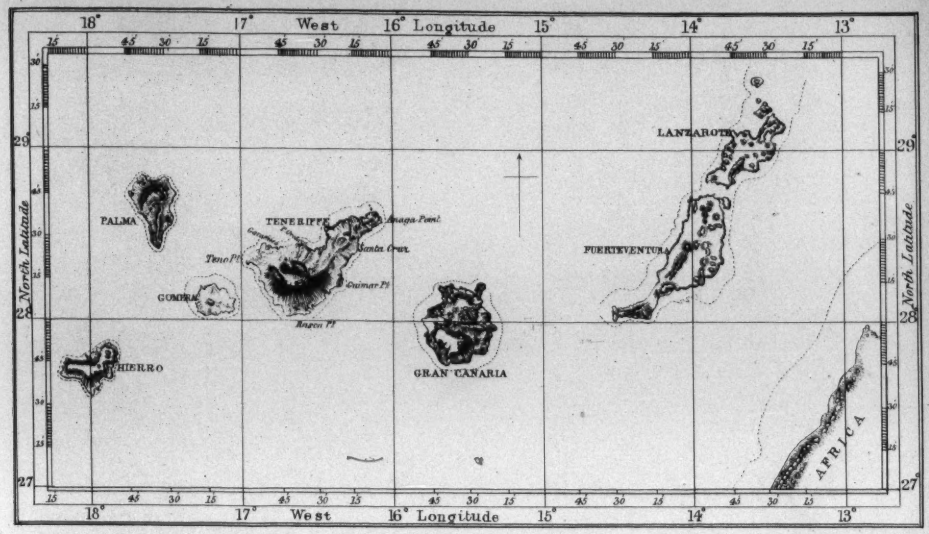
PROPOSED IMPROVEMENTS

in the construction of boiler flues, as derived from experiments.

J. Basire, sc.

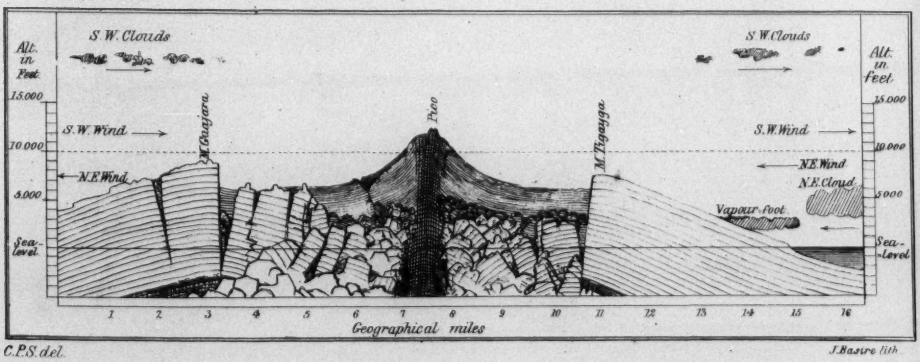
FRANKLIN INSTITUTE LIBRARY

TENERIFFE ASTRONOMICAL EXPERIMENT.



THE CANARY ISLANDS
from the Admiralty Chart
of 1854 & 8.
by Captn Vidal & Lieut Arlett R. N.

FRANKLIN INSTITUTE LIBRARY

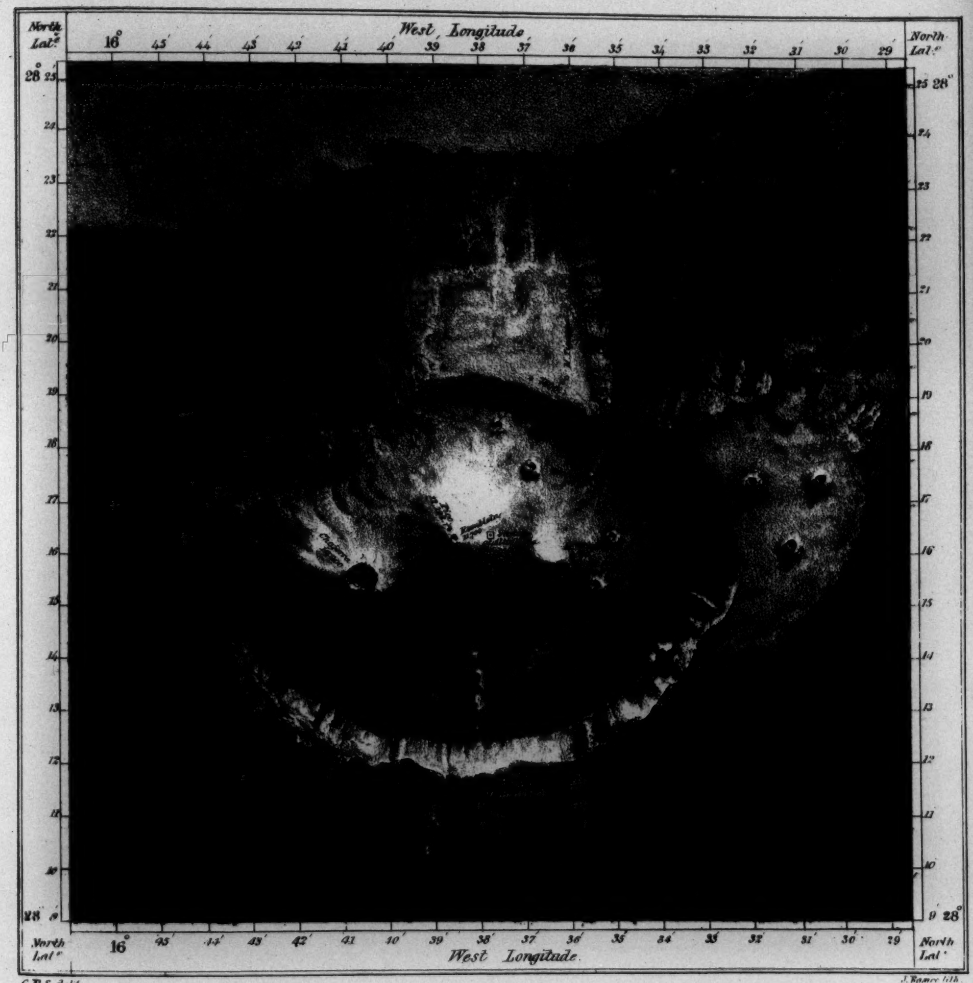


C.P.S. del. J. Basire lith.

Meridional section through the Peak of Teneriffe, and its summer atmosphere.

FRANKLIN INSTITUTE LIBRARY

TENERIFFE ASTRONOMICAL EXPERIMENT.



C. P. S. del.t

J. Basire lith.

PROVISIONAL MAP OF THE PEAK OF TENERIFFE.

Heights in Feet.

The Cloud Horizon Westward from Guajara, shewing the summit of Palma above, and the base of Gomera below the Cloud.

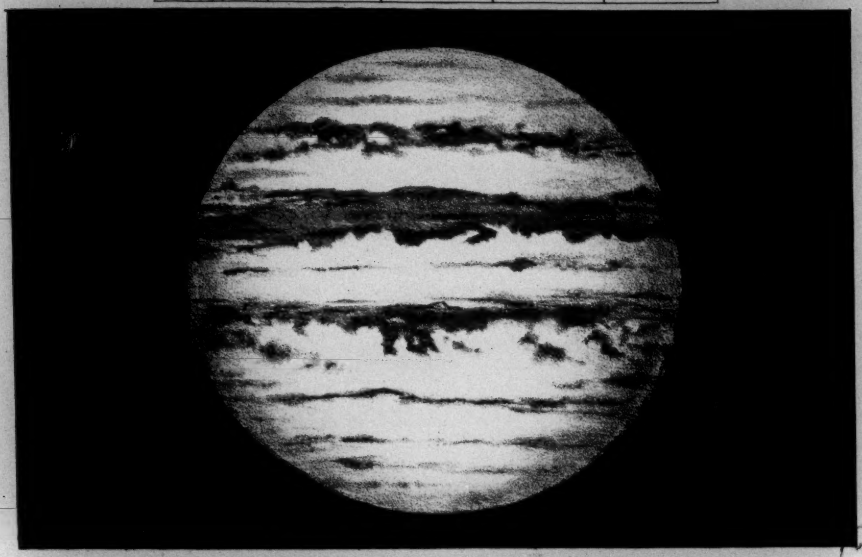
C.P.S. del.t J. Basire lith.

The Cloud Horizon at Guajara as seen by moonlight, showing the summit of Grand Canary above the Clouds in the distance.

TENERIFFE ASTRONOMICAL EXPERIMENT

Scale of Seconds of Space

0 5 10 20 30 40 50



ALTA VISTA STATION — JUPITER

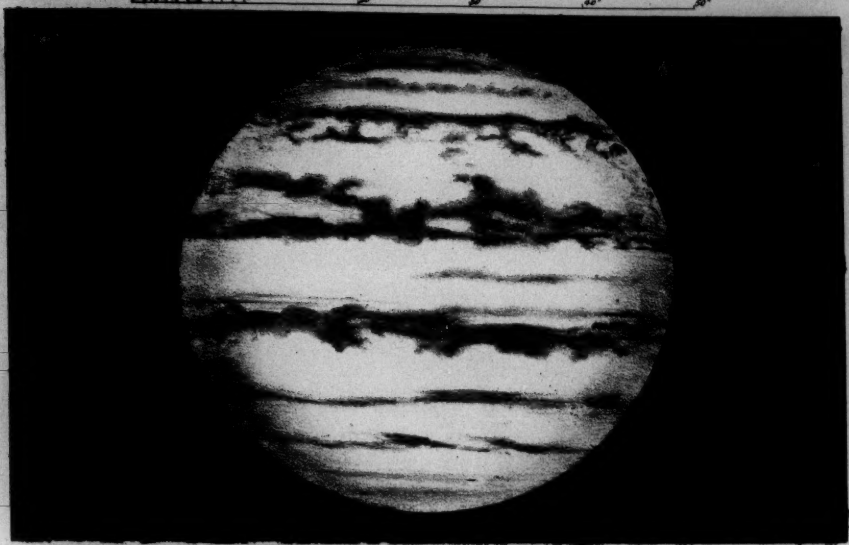
As seen in the Pattinson Equatorial with magnifying power 350 at 23h Sid. Time on September 4th 1856

FRANKLIN INSTITUTE LIBRARY

C.P.S. del. J. Basire, lith.

ALTA VISTA STATION — JUPITER

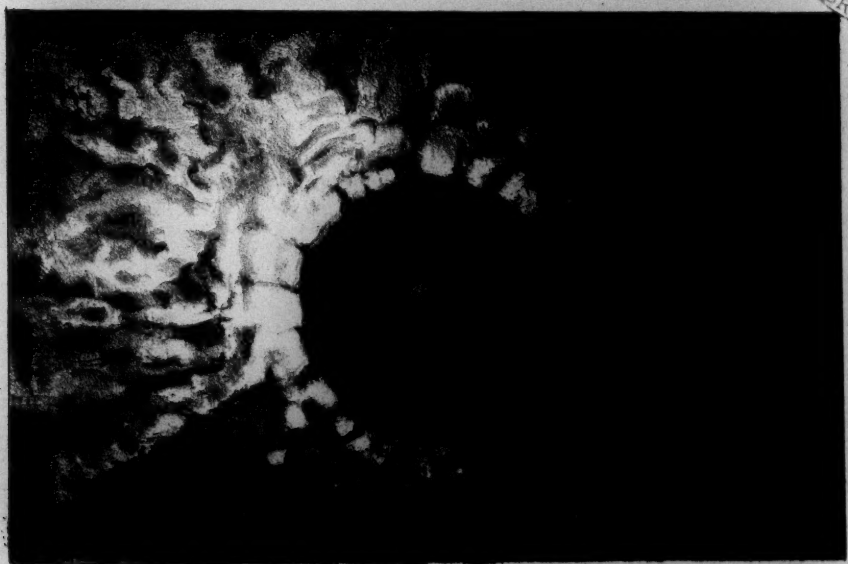
At 23h. 30m. Sid. Time on September 5th 1856 Meridian 170° difference from drawing of Sep.r 4th.



ALTA VISTA STATION. — JUPITER.

At 0h 30m Sid. Time on September 6th 1856. Meridian same as on the 4th of Sept.

FRANKLIN INSTITUTE LIBRARY.



C.P.S. del. Scale of Seconds of Space. J. Basire lith.

Scale of English Miles

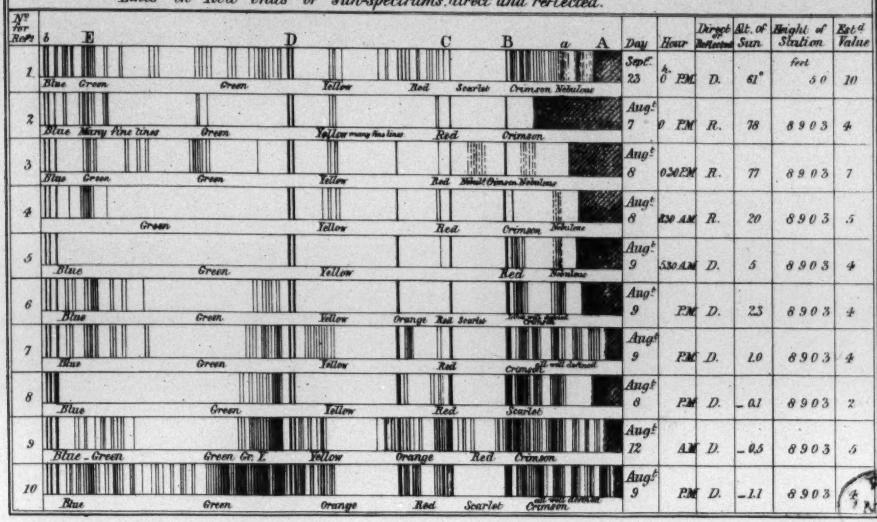
ALTA VISTA STATION

Approximate Drawing of Aristolychus in the Moon magnifying power 260. September 6th 1856.

TENERIFFE ASTRONOMICAL EXPERIMENT.

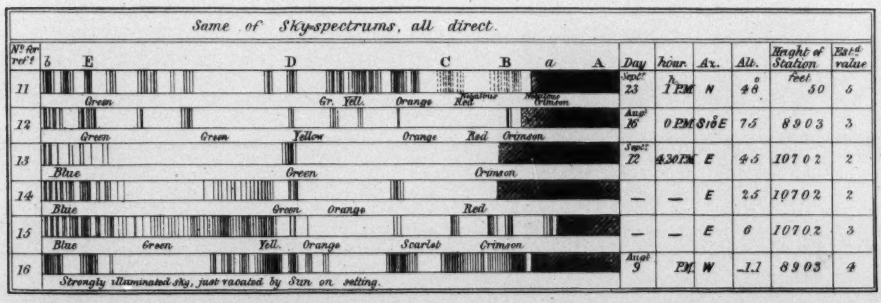
P.P. 1.

Lines in Red ends of sun-spectrums, direct and reflected.



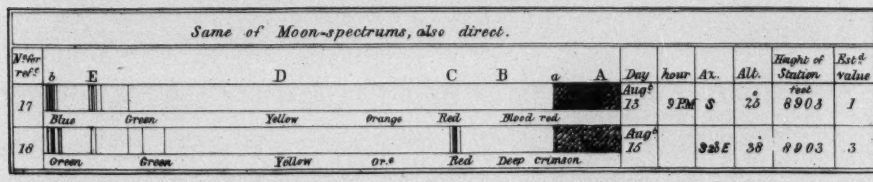
No. for Ref.	Day	Hour	Direct or Reflected	Alt. of Sun	Height of Station	Est.d Value
1	Sept.r 23	h. 0 PM	D.	61°	feet 50	10
2	Aug.t 7	0 PM	R.	78	8903	4
3	Aug.t 8	0.20 PM	R.	77	8903	7
4	Aug.t 8	8.30 AM	R.	20	8903	5
5	Aug.t 9	5.30 AM	D.	5	8903	4
6	Aug.t 9	PM	D.	23	8903	4
7	Aug.t 9	PM	D.	1.0	8903	4
8	Aug.t 8	PM	D.	−0.1	8903	2
9	Aug.t 12	AM	D.	−0.5	8903	5
10	Aug.t 9	PM	D.	−1.1	8903	4

Same of Sky-spectrums, all direct.



No. for ref.t	Day	hour	Az.	Alt.	Height of Station	Est.d value
11	Sept.r 23	h. 1 PM	N	46°	feet 50	5
12	Aug.t 16	0 PM	S 16° E	75	8903	3
13	Sept.r 22	4.30 PM	E	45	10702	2
14	—	—	E	25	10702	2
15	—	—	E	0	10702	3
16	Aug.t 9	PM	W	−1.1	8903	4

Same of Moon-spectrums, also direct.

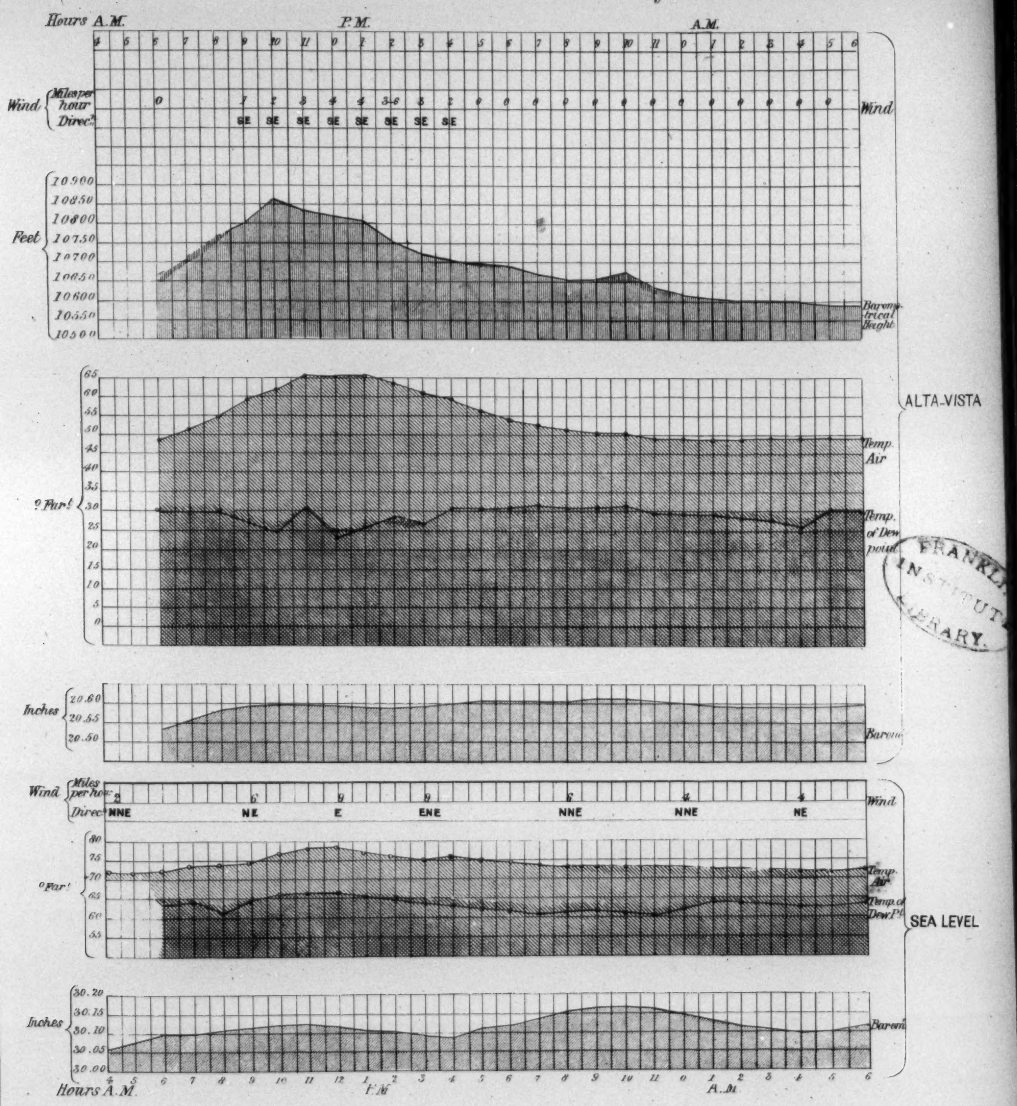


No. for ref.s	Day	hour	Az.	Alt.	Height of Station	Est.d value
17	Aug.t 13	9 PM	S	25°	feet 8903	1
18	Aug.t 15		S 25° E	38°	8903	3

J. Basire lith.

FRANKLIN INSTITUTE LIBRARY

Comparison of hourly Variations at the Sea-level, and at Alta Vista on August 21st. M.P.2.



J. Basire lith.

FRANKLIN INSTITUTE LIBRARY.

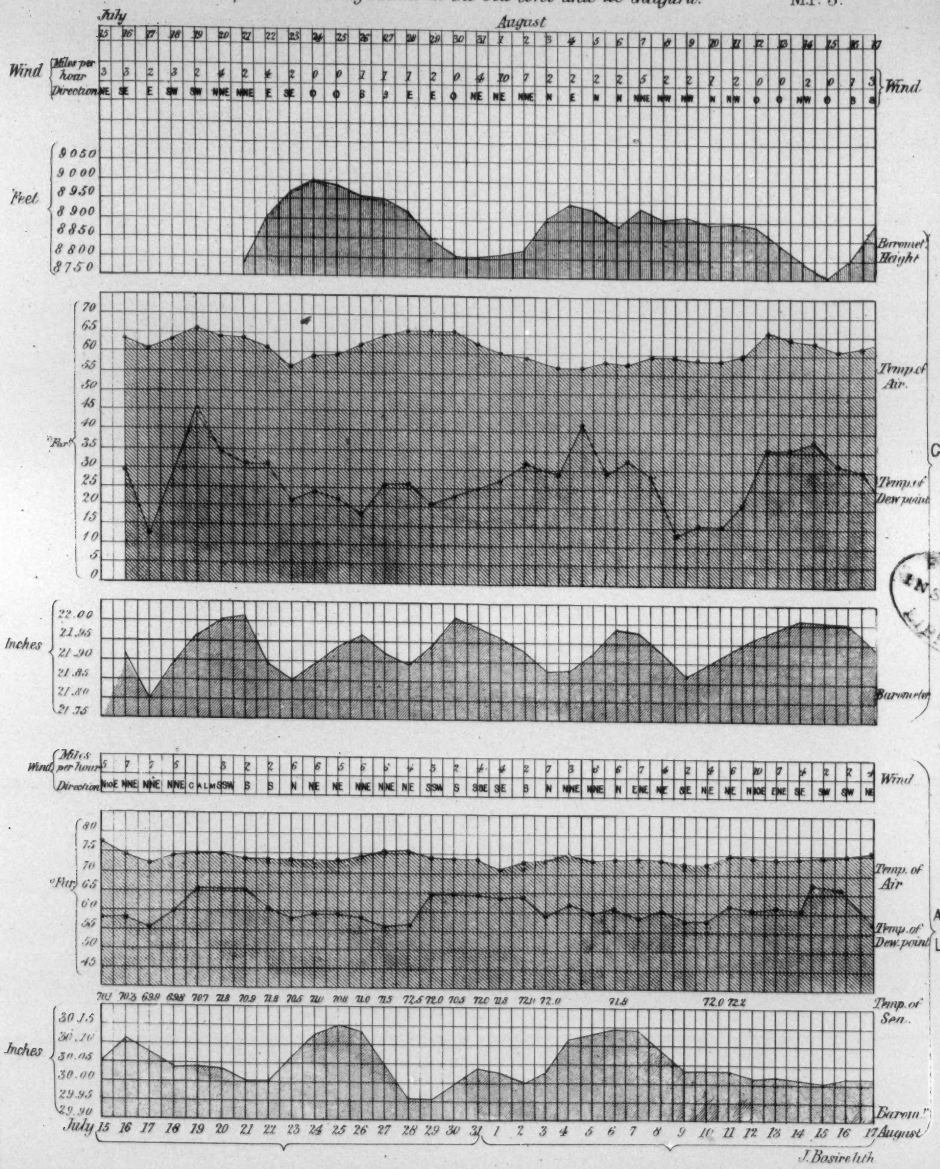
W

W

Inc

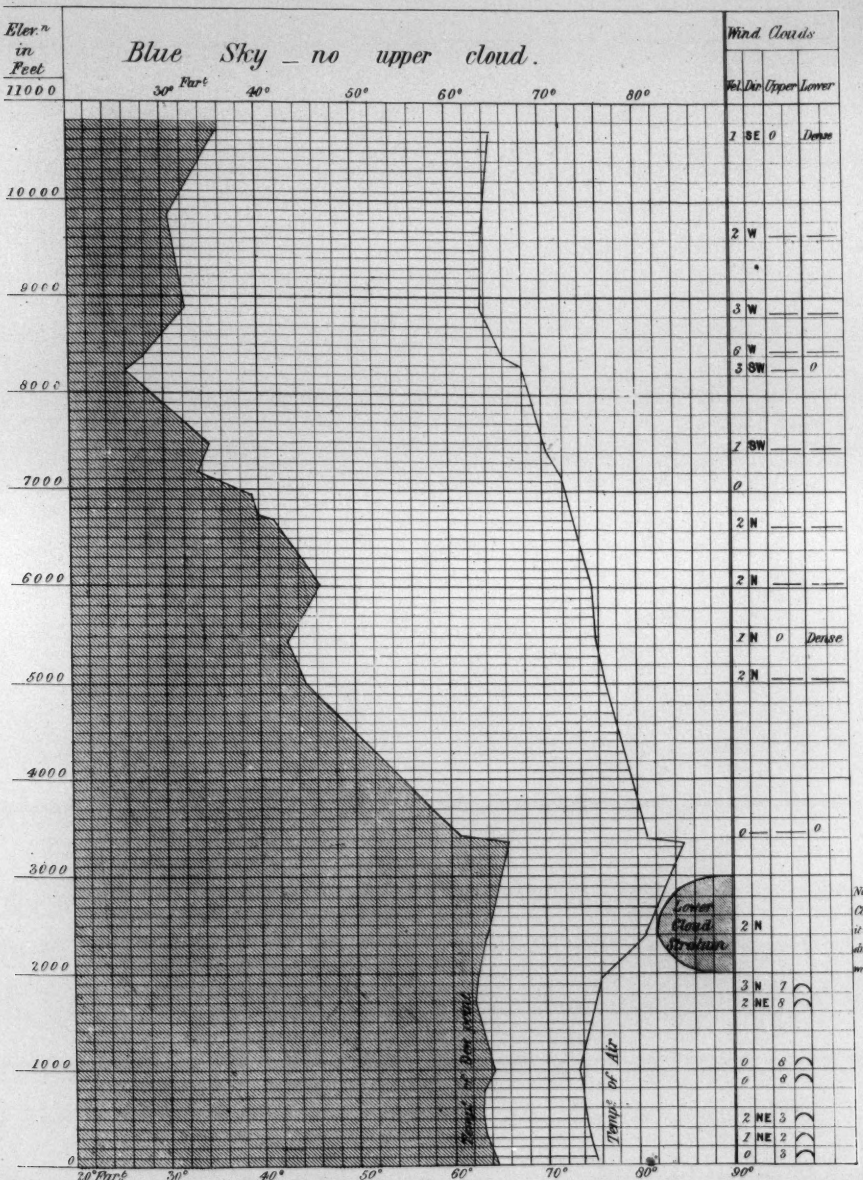
Inc

Comparison of Daily Means at the Sea-level and at Guajara. M.P. 3.



FRANKLIN INSTITUTE LIBRARY

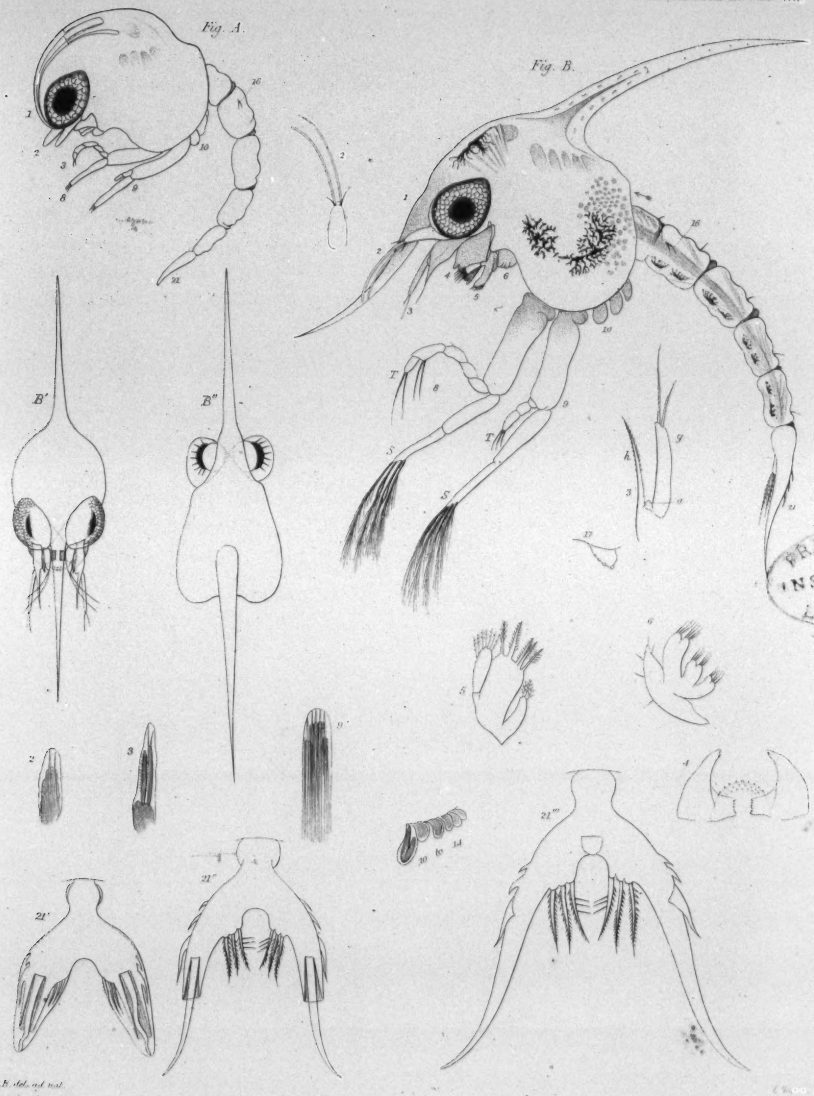
Meteorological descent from Alta Vista to Orotava 25th August 1856. M.P. 5.



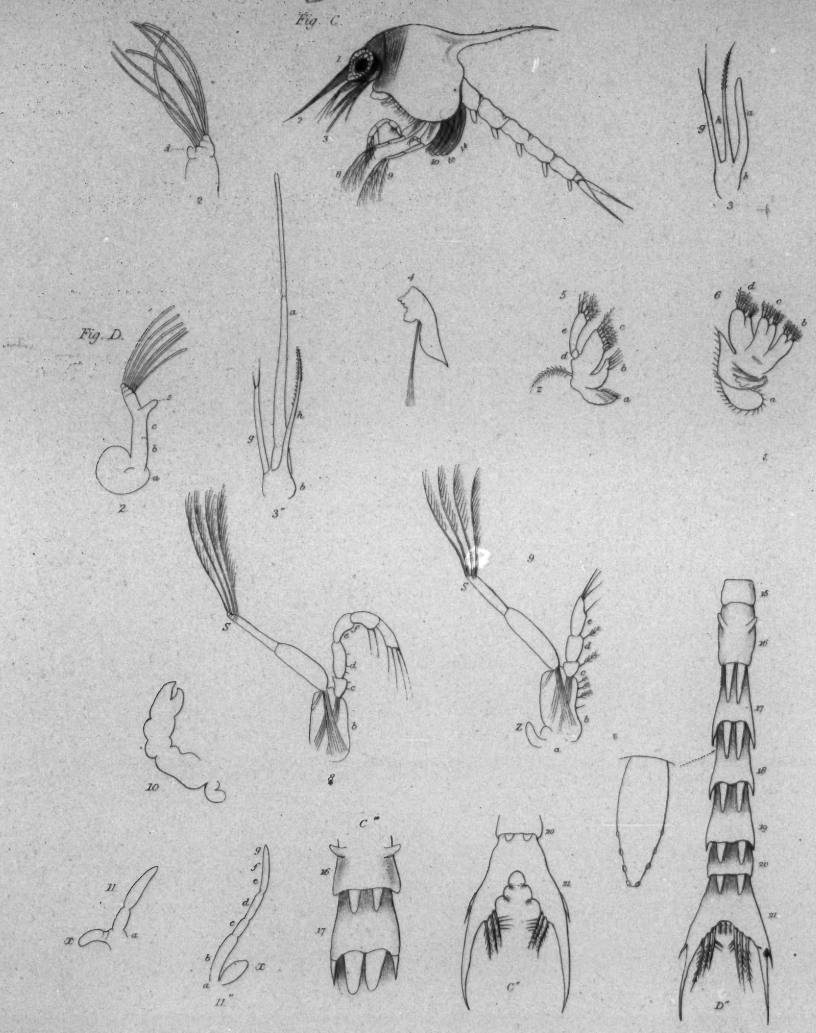
TENERIFFE ASTRONOMICAL EXPERIMENT. *Phil. Trans. MDCCCLVIII. Plate XXXIX.*

Meteorological ascent from Orotava to Alta Vista 30th August, 1856. M. P. 6.

FRANKLIN INSTITUTE LIBRARY



FRANKLIN INSTITUTE LIBRARY

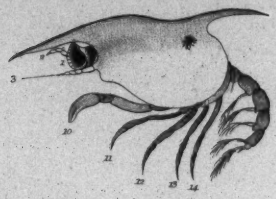


S. B. del. ad. nat.

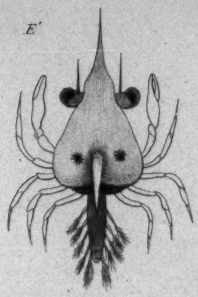
J. Basire, sc.

AMST LIBRARY

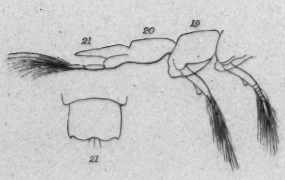
Fig. E.



E'

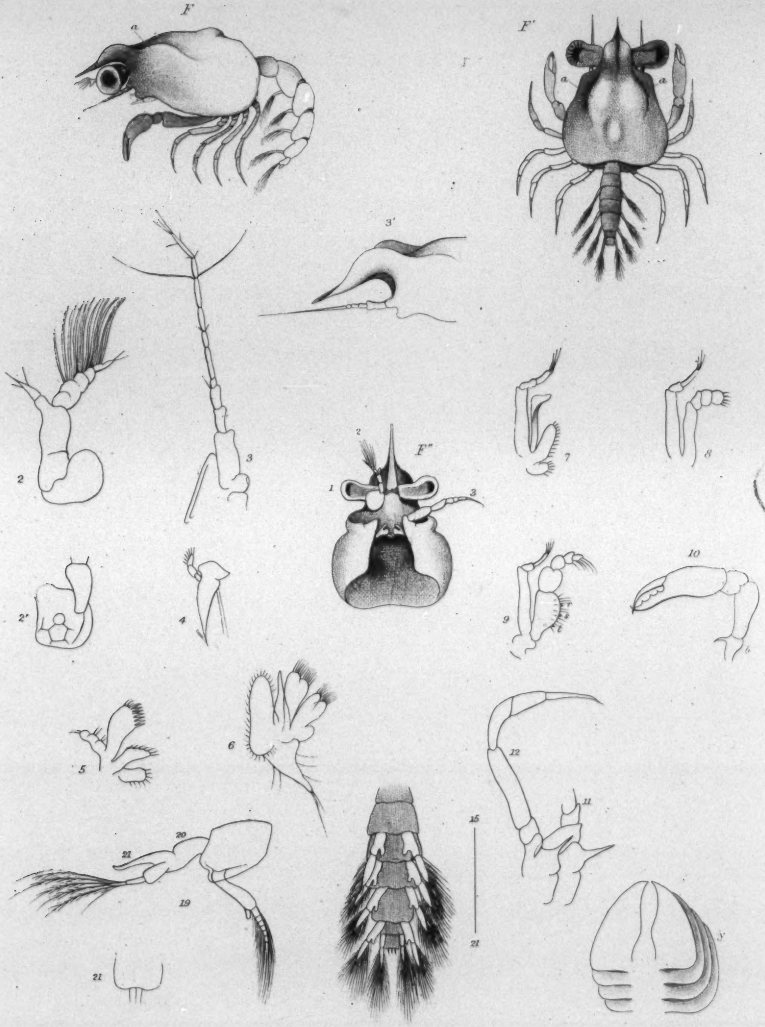


FRANKLIN INSTITUTE LIBRARY



E''

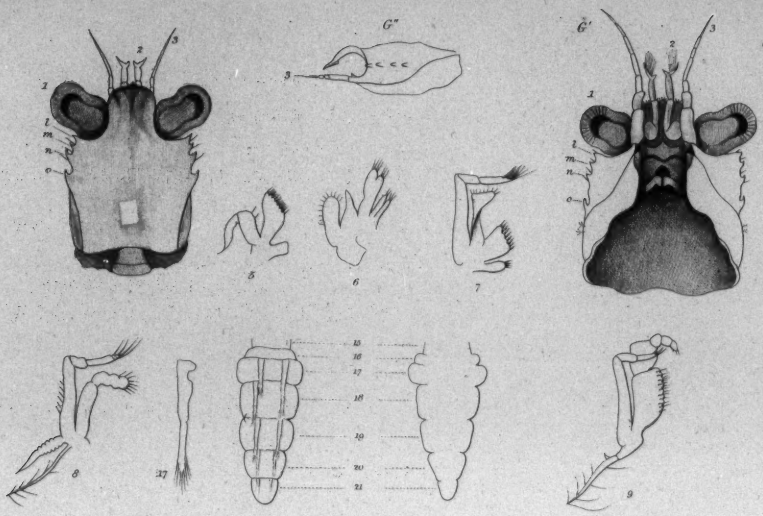
J. Basire sc.



FRANKLIN INSTITUTE LIBRARY

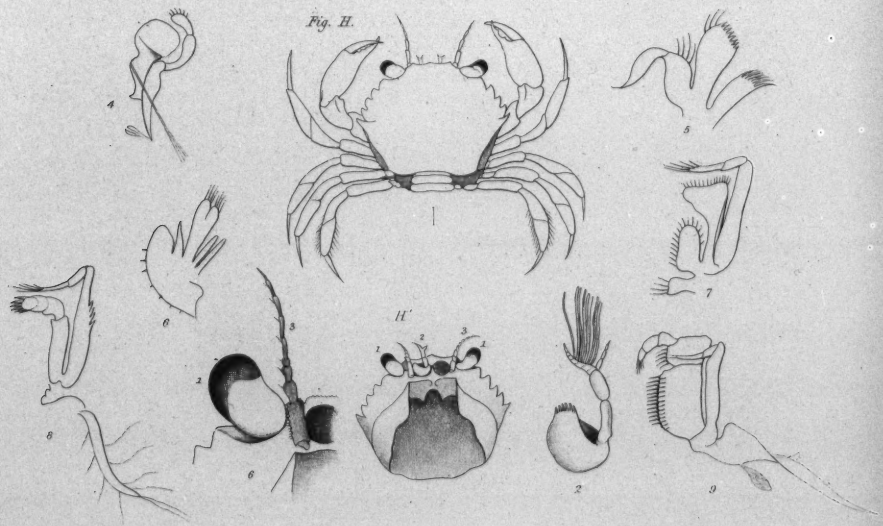
J. Basire

Fig. G.



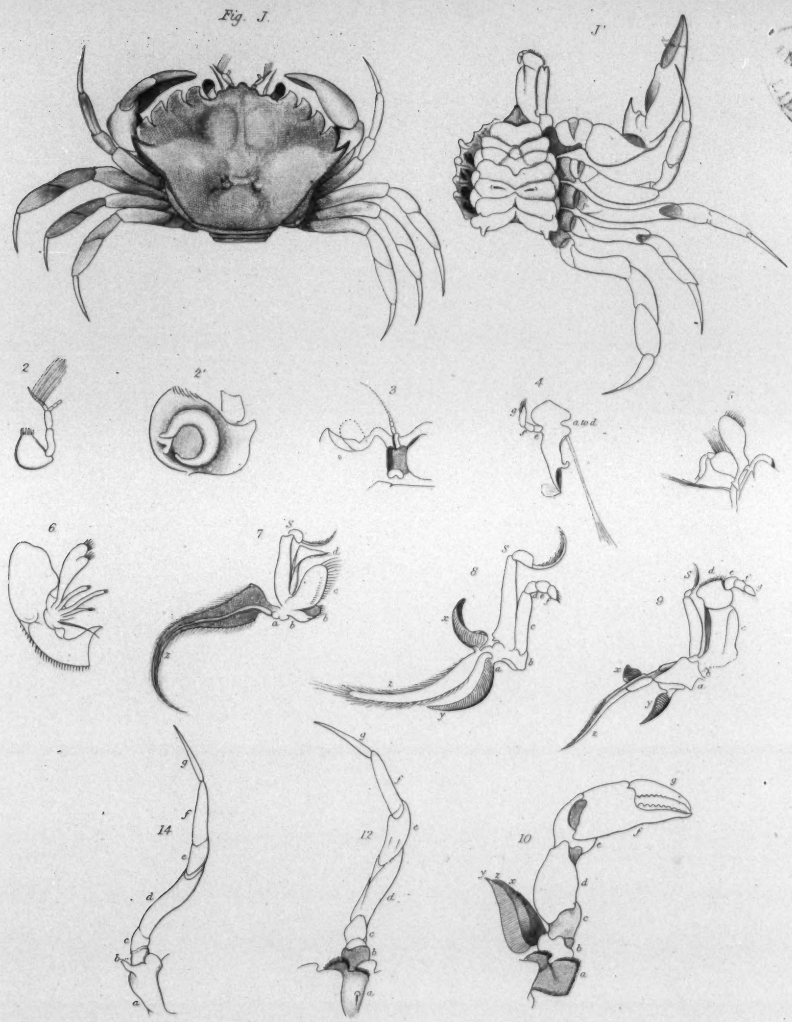
FRANKLIN INSTITUTE LIBRARY.

Fig. H.

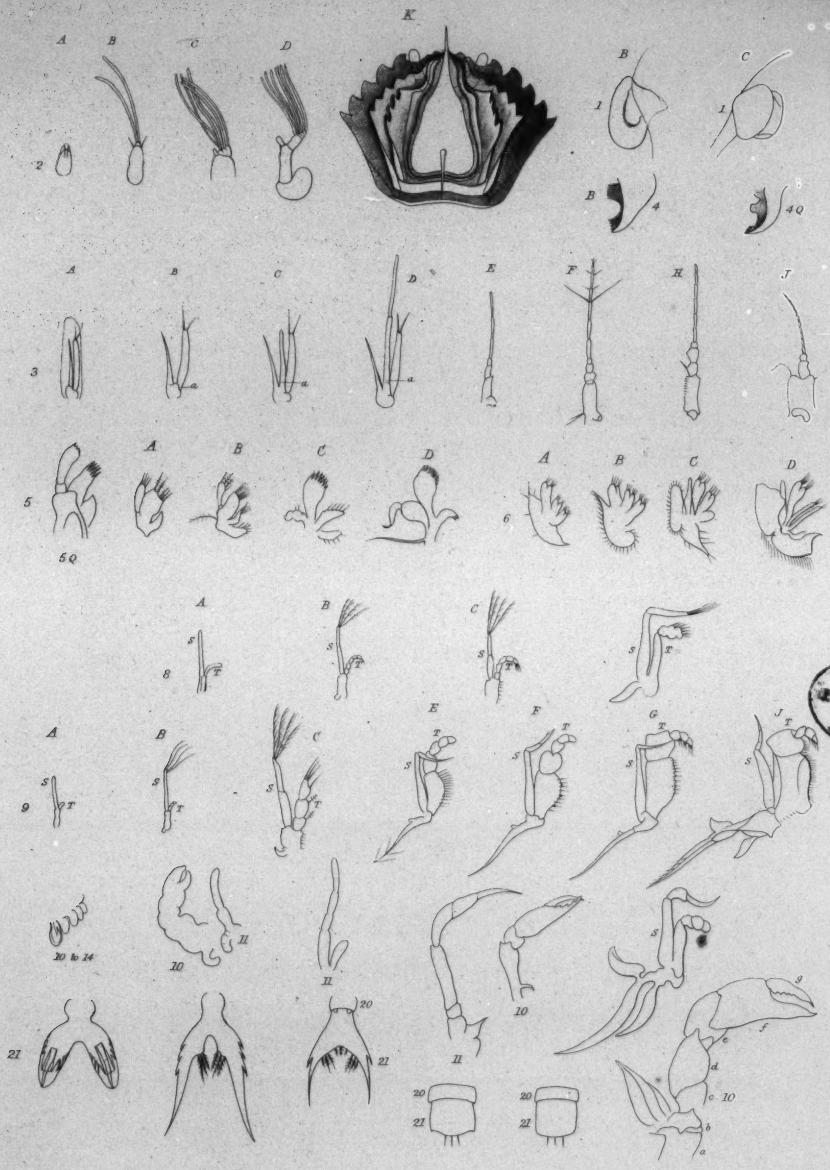


J. Basire, sc.

FRANKLIN INSTITUTE LIBRARY.

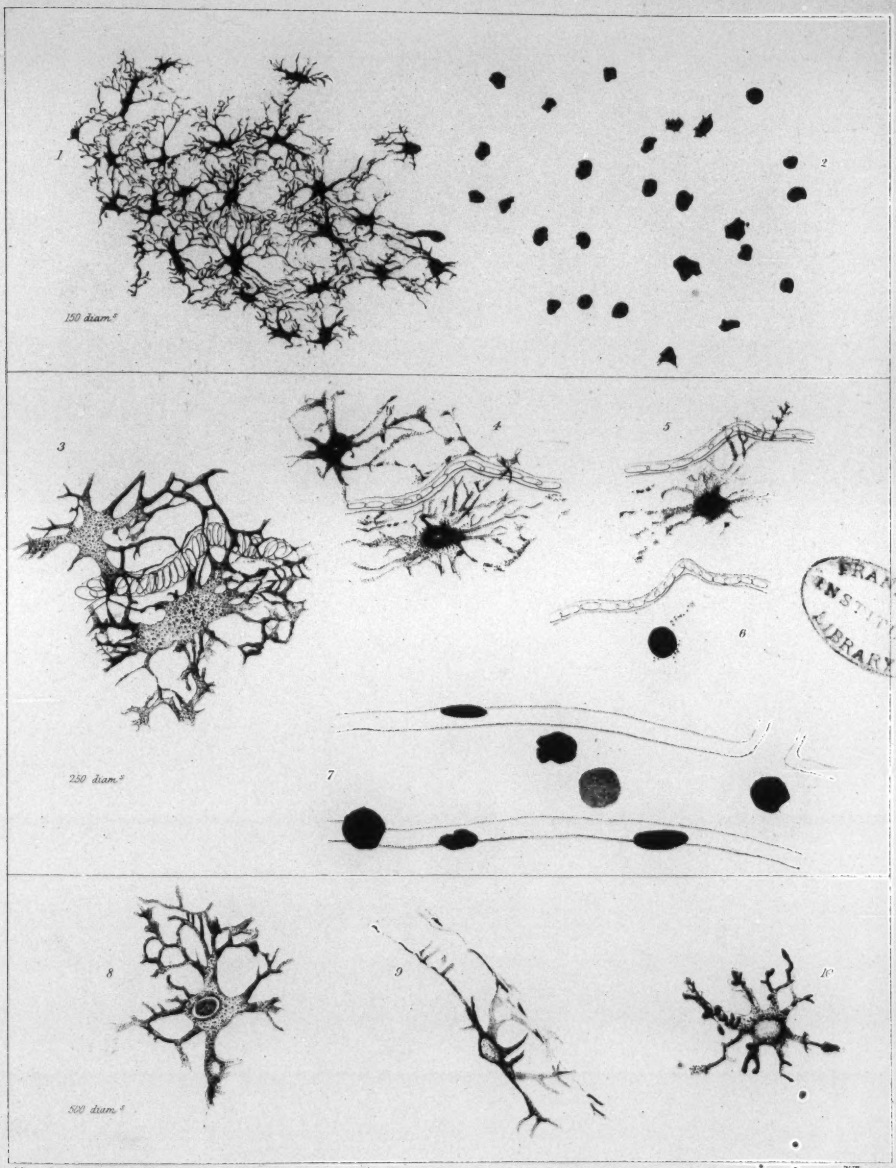


J. Basire



FRANKLIN INSTITUTE LIBRARY

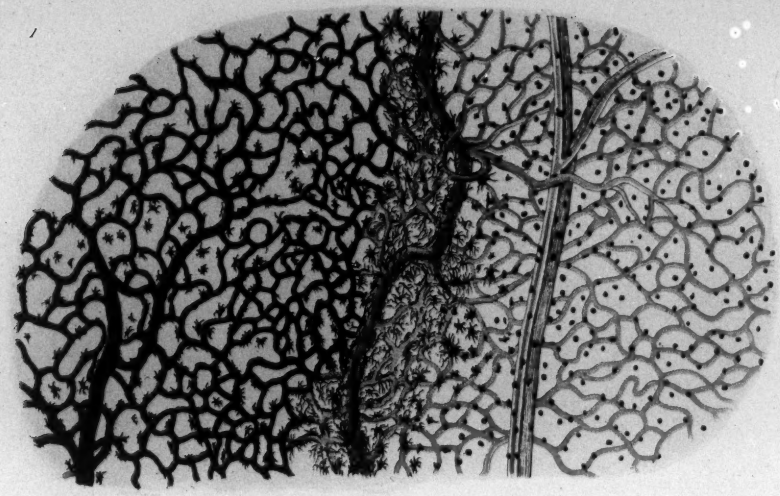
J. Basire, sc.



FRANKLIN INSTITUTE LIBRARY

J. Lucas del. Duffin, West sculp. W. West, imp.

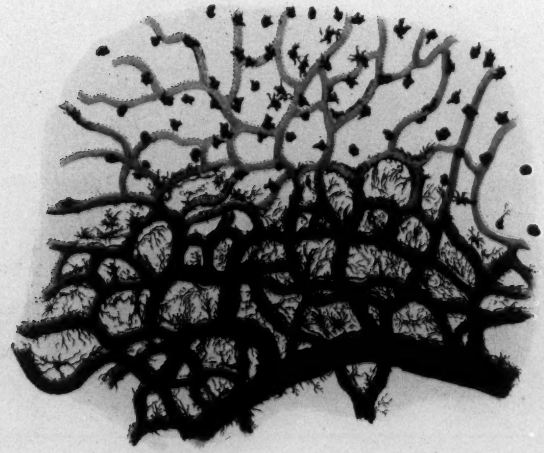
1



35 diam.r

FRANKLIN INSTITUTE LIBRARY

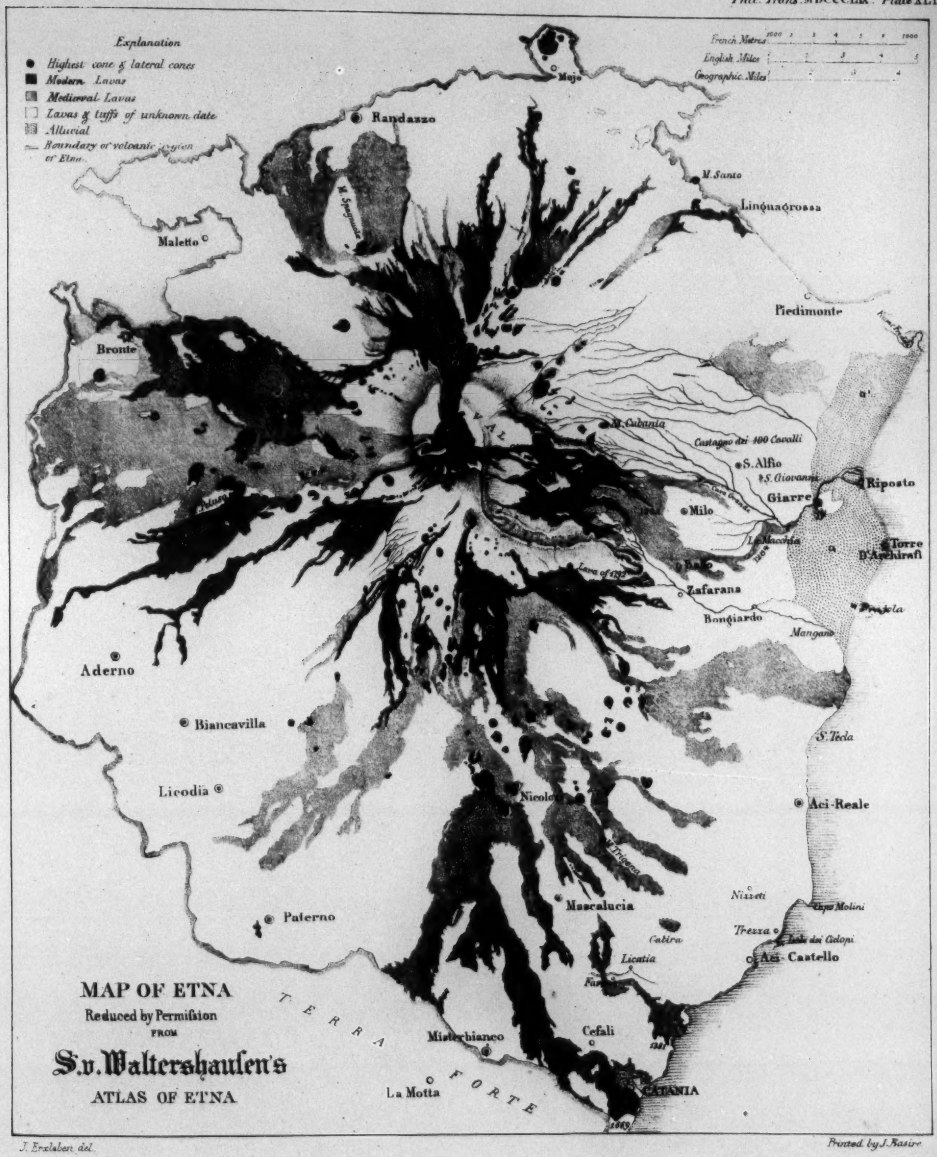
2



90 diam.r

Fraser del. Dalton Wm. sculp.

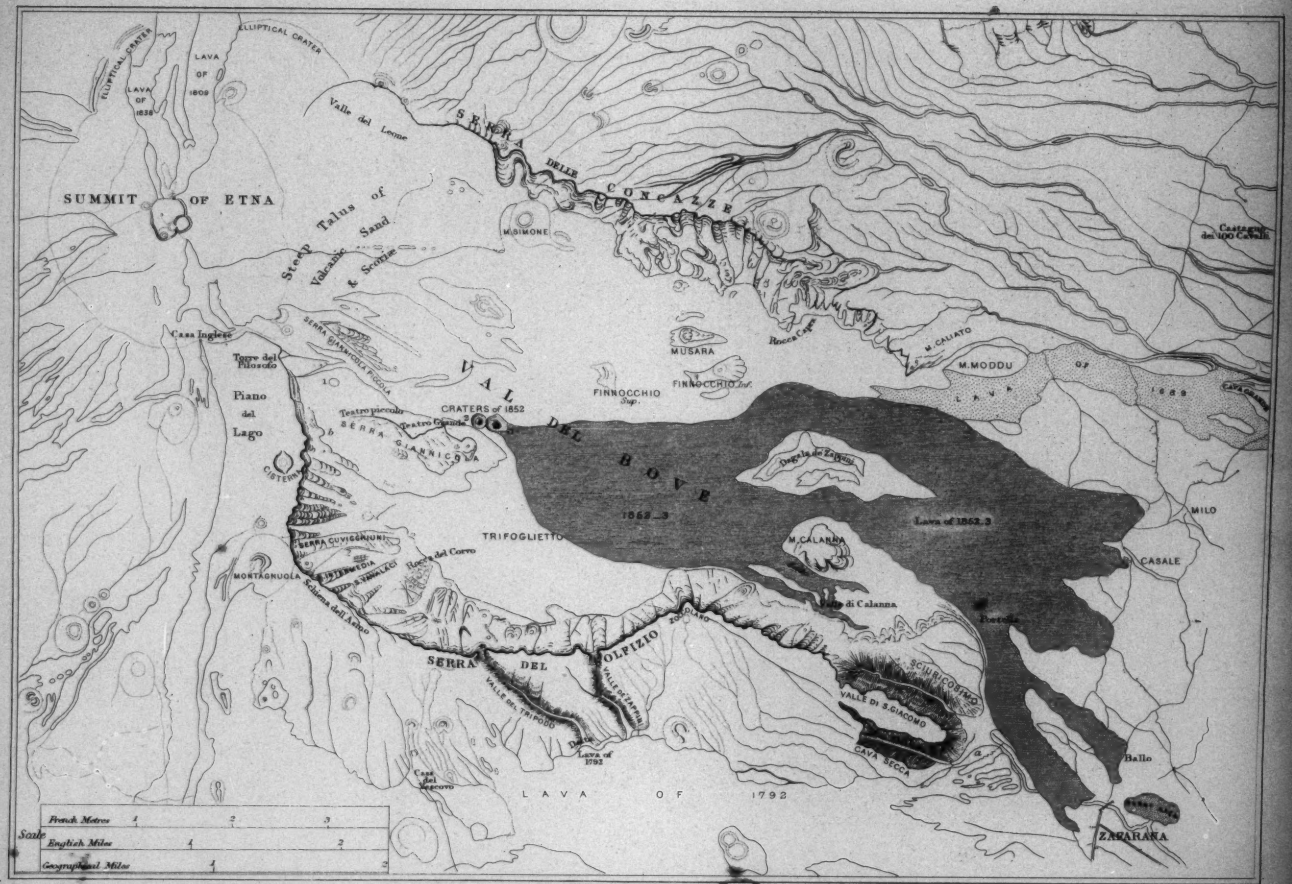
Wm. Clowes imp.



MAP OF ETNA
Reduced by Permission
FROM
S.v. Waltershausen's
ATLAS OF ETNA

J. Erxleben del.

Printed by J. Basire

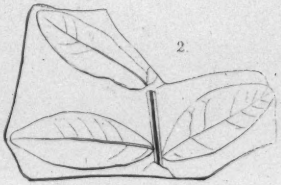


CRATERS AND LAVA OF 1852. & 1853.

The Outlines of the Map taken from Sir Neil Walter Sahatten's Atlas of Etna.

J. Basire Sc.

Fossil leaves from the tuff of Fasano, Etna,
from drawings by Prof.r O. Heer.



1. 2. Pistacia Lentiscus L.
Etna.

6.
variet. latifolia.

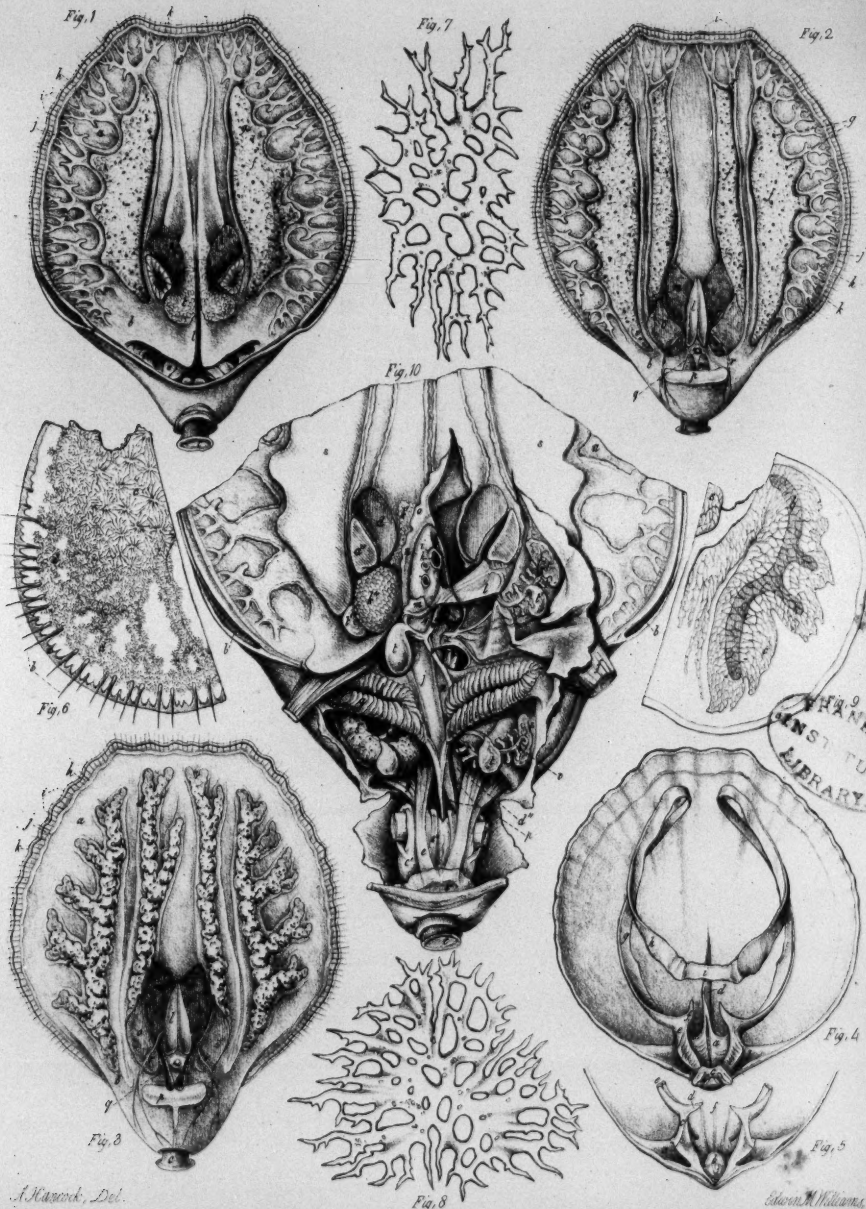
3. Laurus nobilis L.
Etna.

4. 5. Myrtus communis L.
Etna.

TRANS. INSTITU LIBRARY

J. Endeben on Stone.

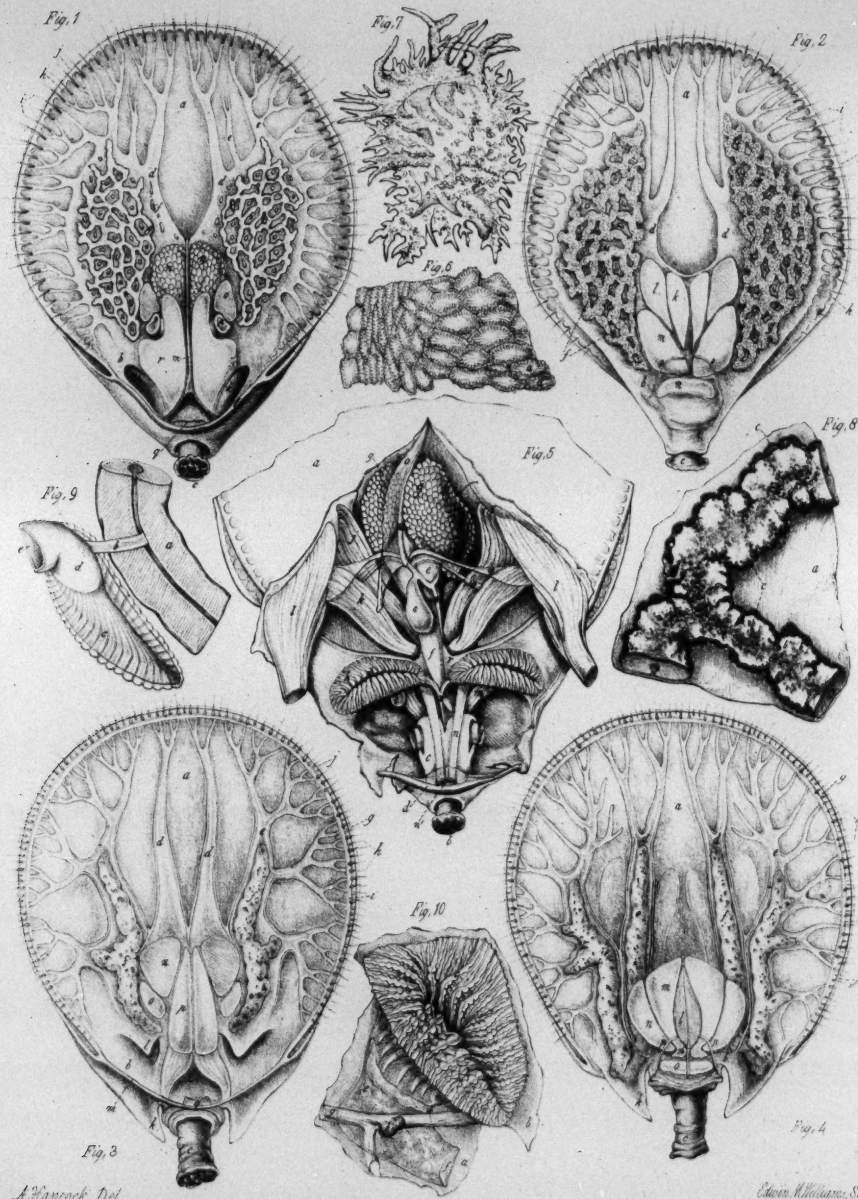
Printed by J. Reeves.



FRANKLIN INSTITUTE LIBRARY

A. Hancock, Del.

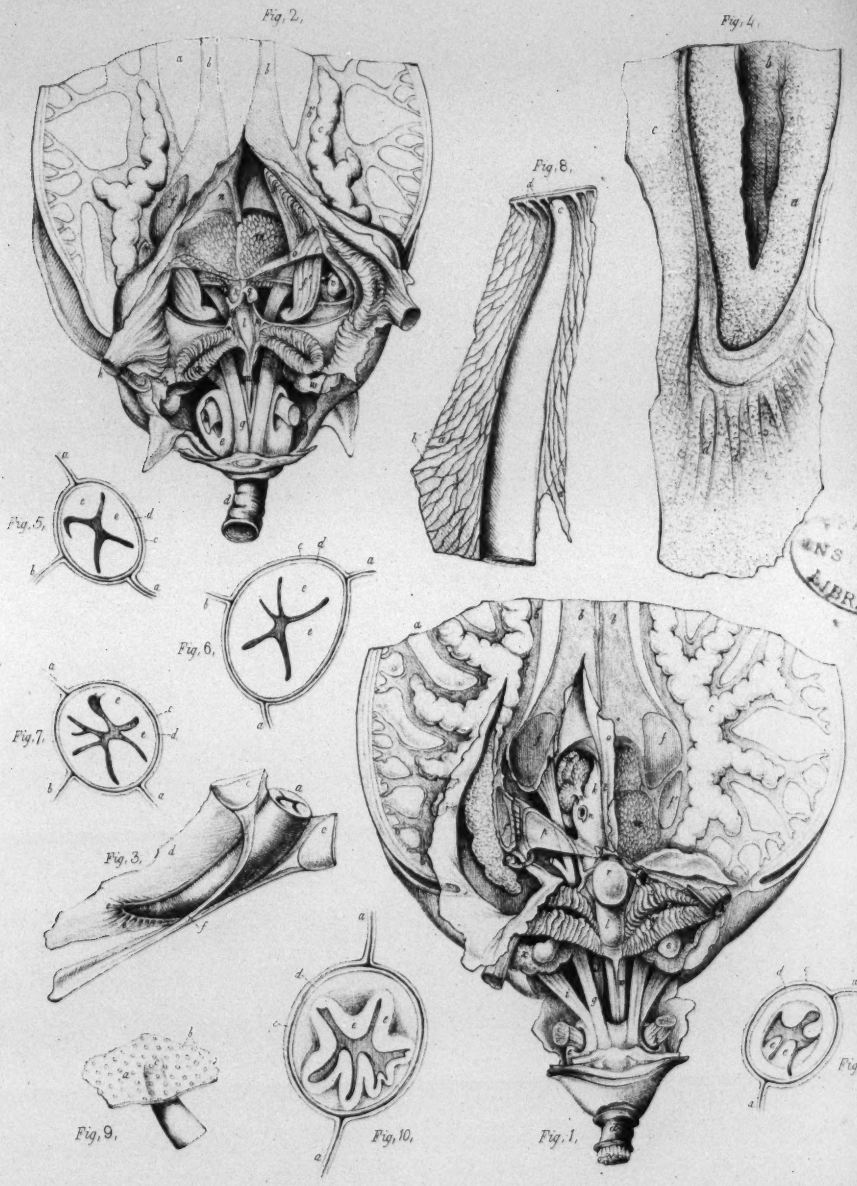
Edward M. Williams, Sc.



A. Hancock, Del.

Edwin W. Williams, Sc.

Printed by J. Basire



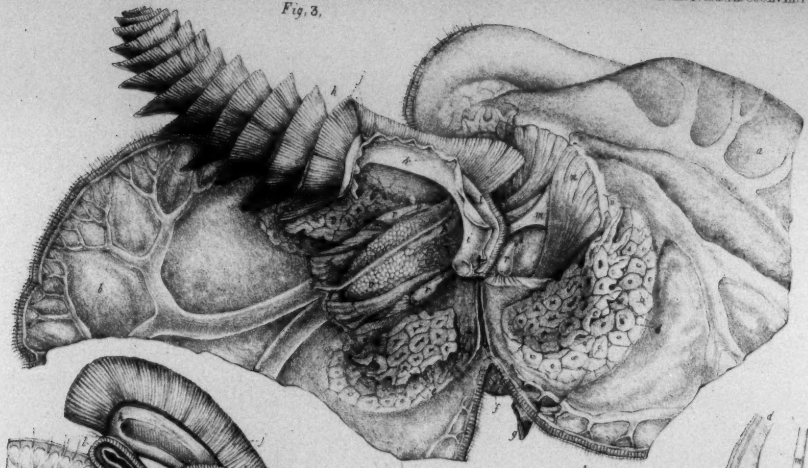
FRANKLIN INSTITUTE LIBRARY

A. Hancock, Del.

Printed by J. Basire.

Edwin N. Williams, Sc.

Fig. 3.



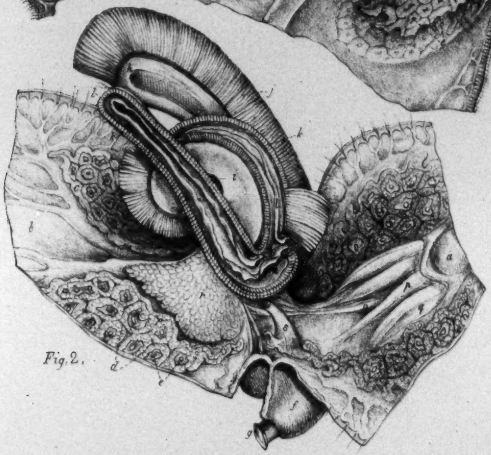


Fig. 2.

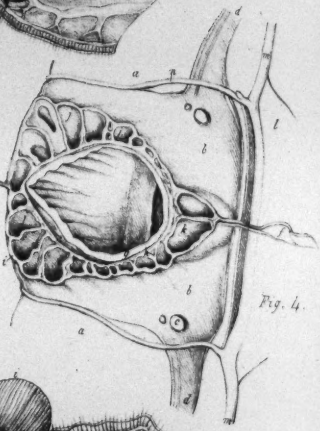


Fig. 4.

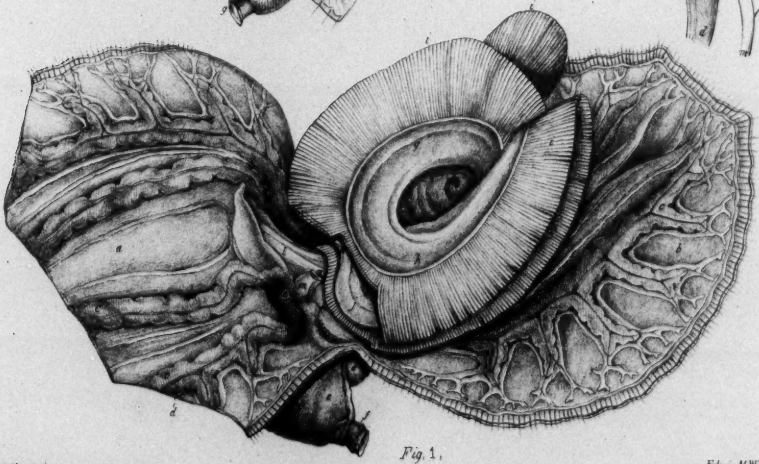
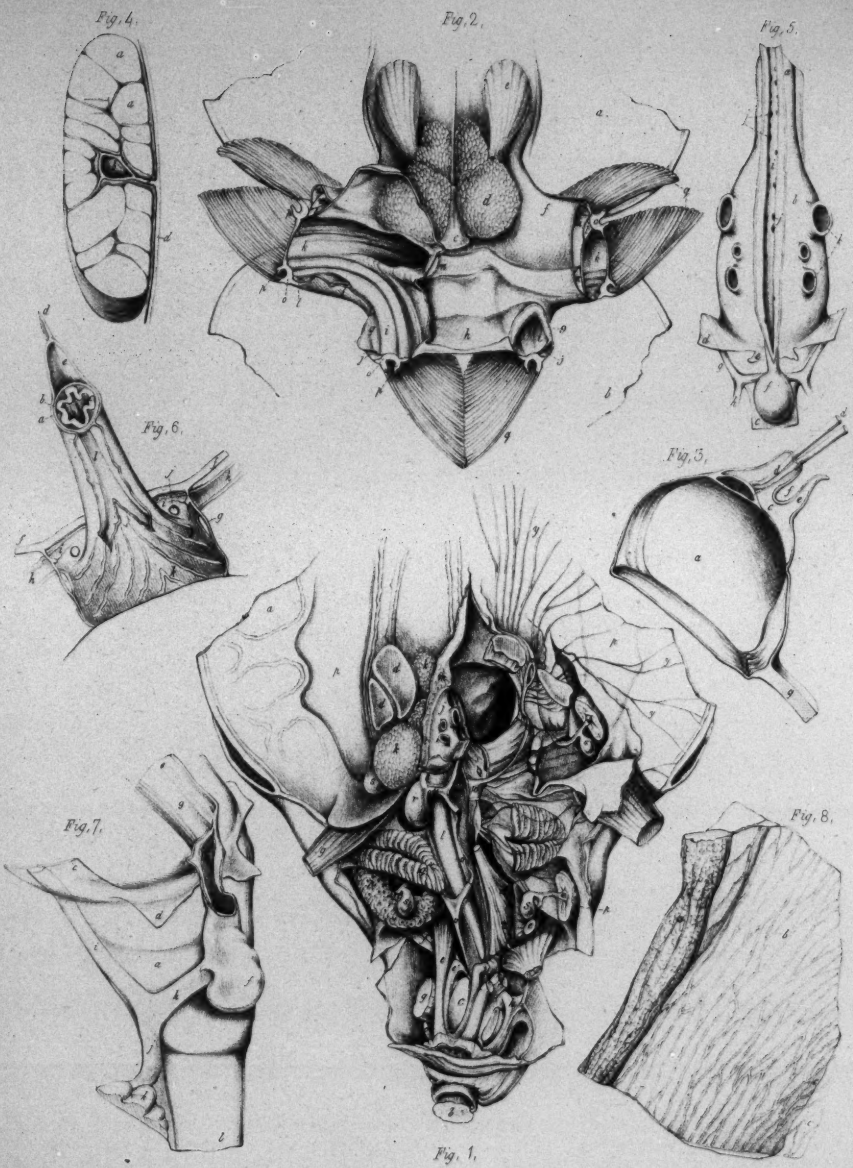


Fig. 1.

A. Hancock, del.

Edwin M. Williams, Sc.

Printed by J. Barlow.

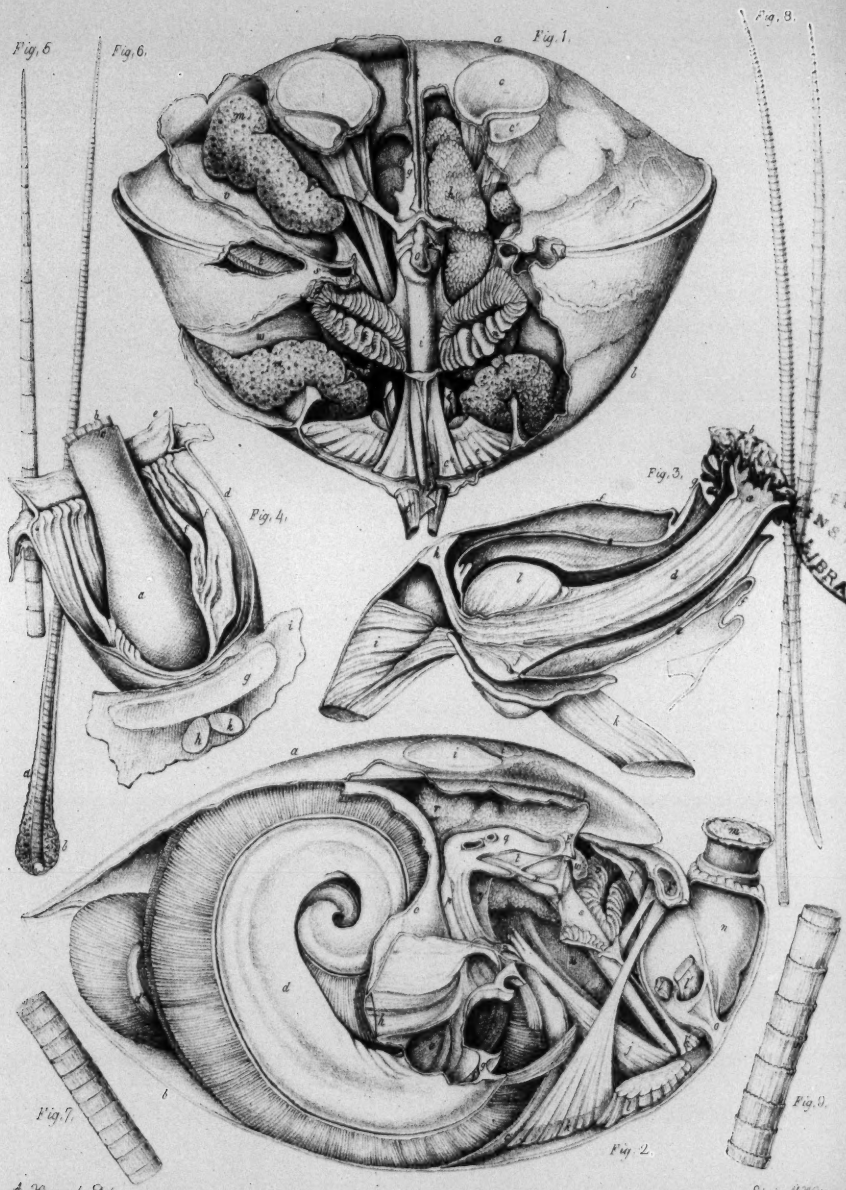


FRANKL
INSTITU
LIBRARY

A. Hancock, Del.

Edwin M. Williams, Sc.

Printed by J. Basire.

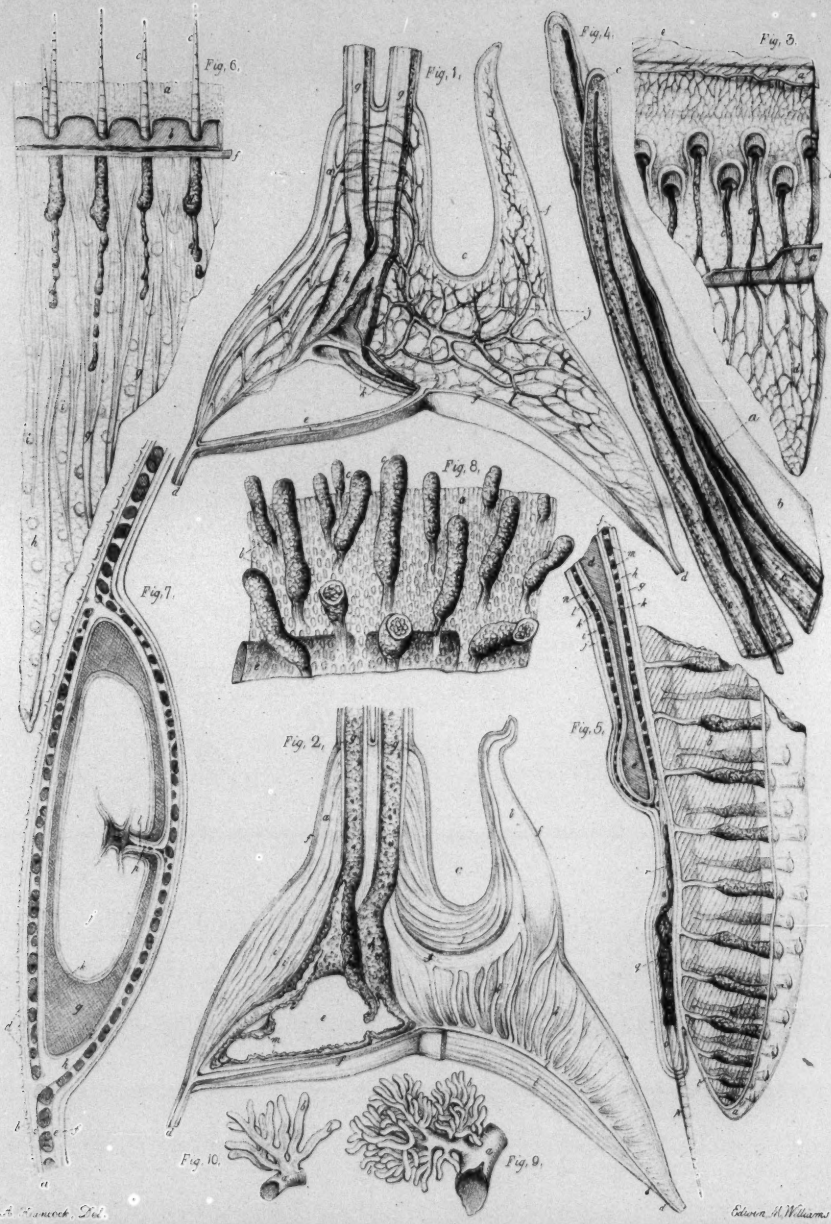


FRANK INSTITUTE LIBRARY

A. Hancock, Del.

Edwin M. Williams, Sc.

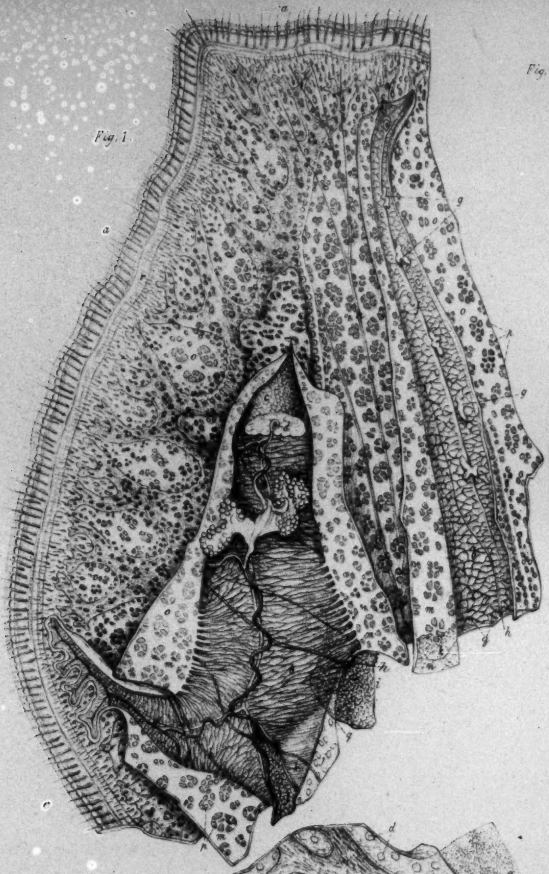
Printed by J. Basire.

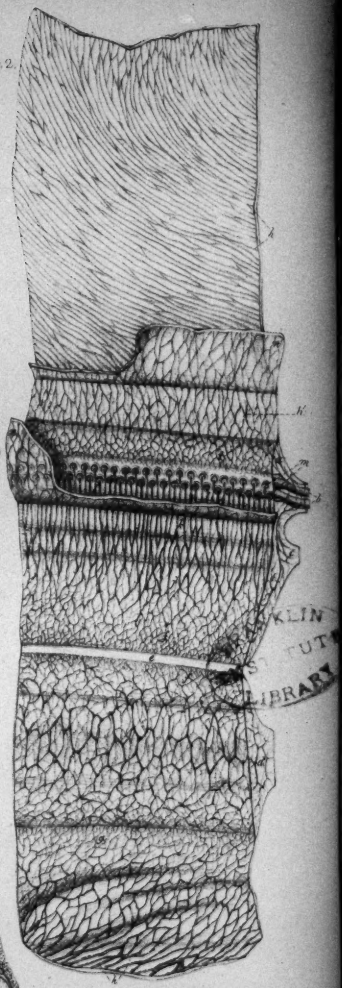


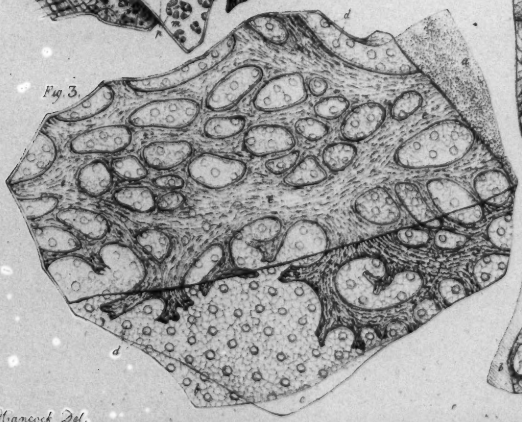
A. Hancock, Del.

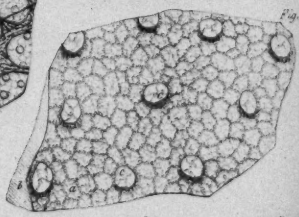
Edwin H. Williams, Sc.

Printed by J. Basire.







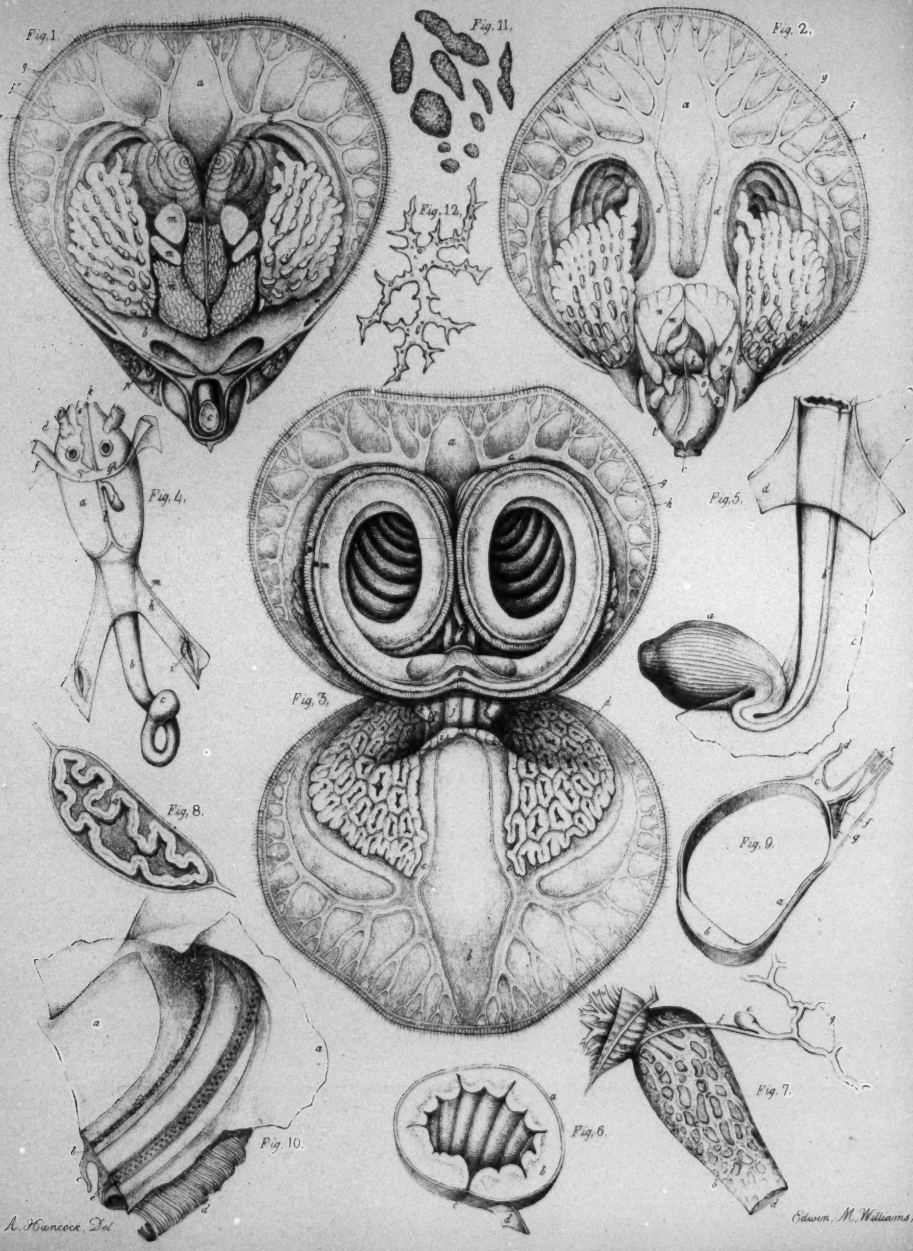


A. Hancock Del.

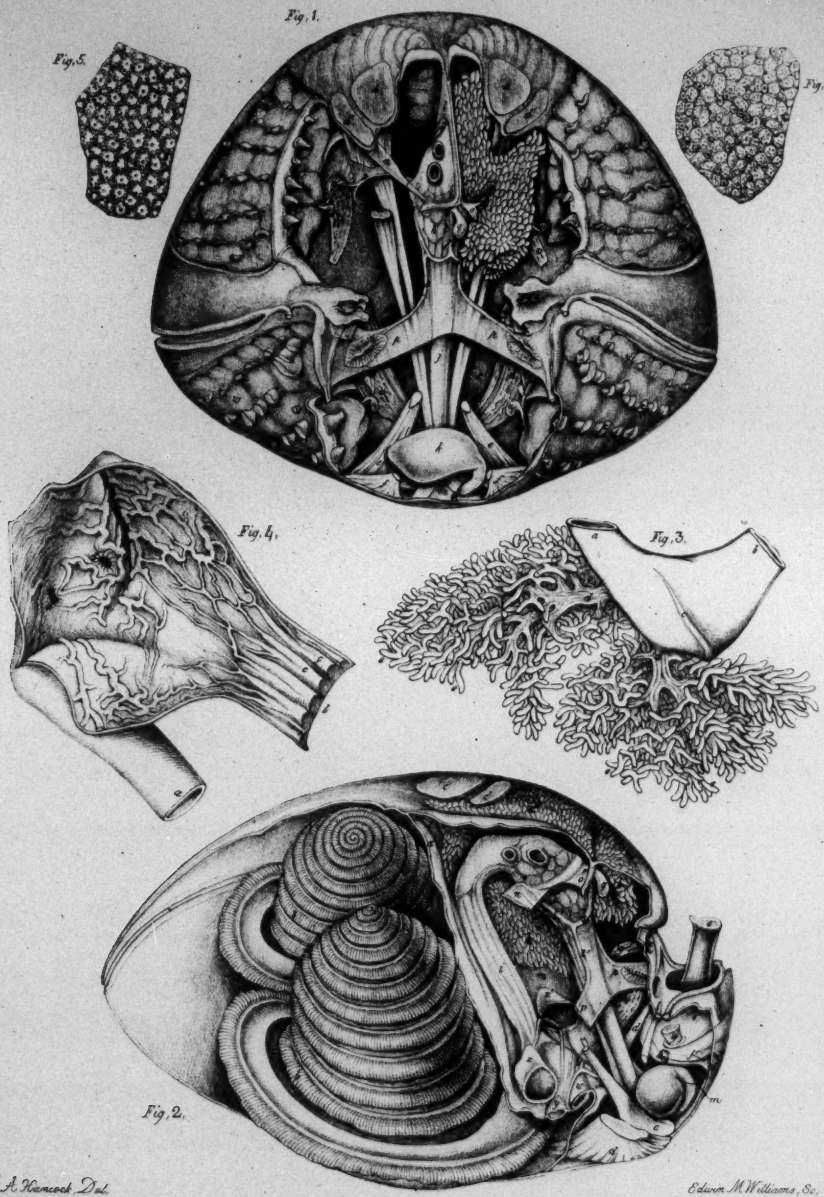
Edwin M. Williams Sc.

KLIN
TUT
LIBRARY

Printed by J. Basire



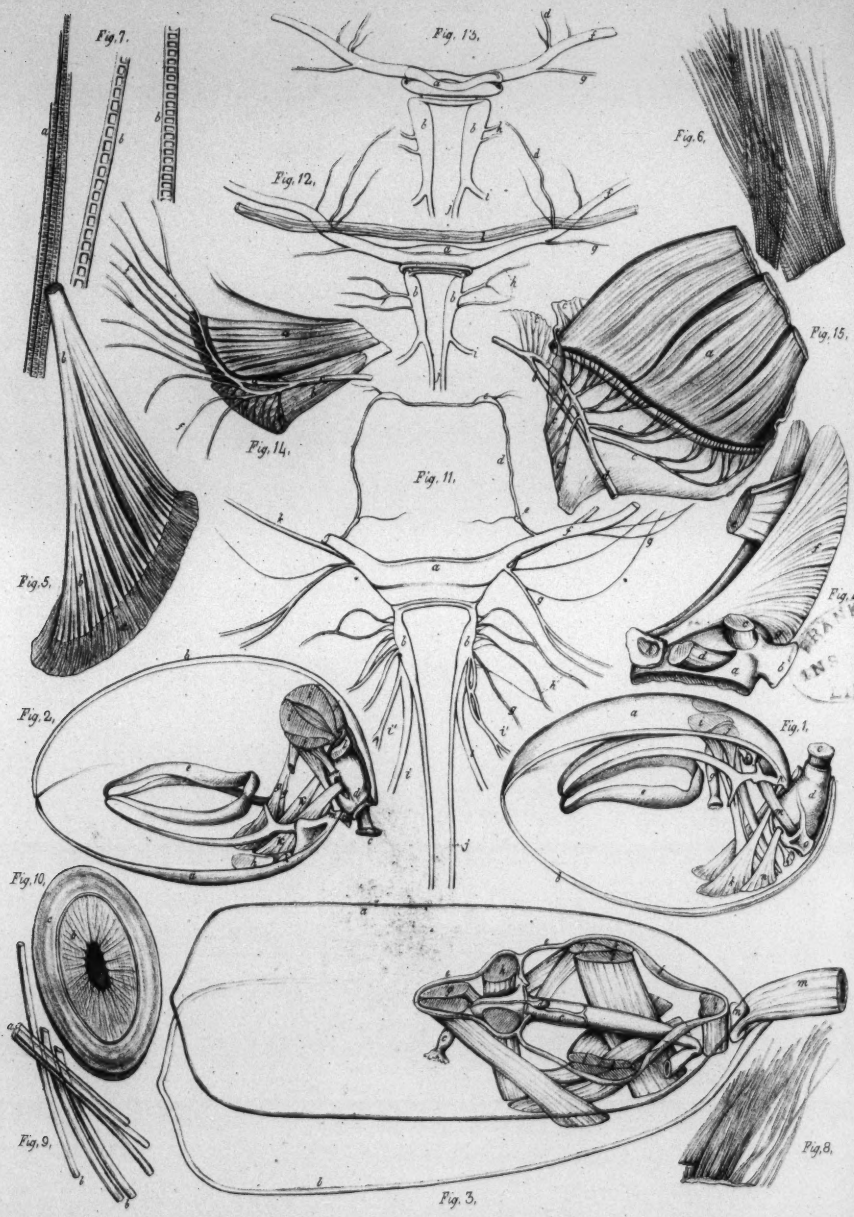
Printed by J. Basire.



A. Hancock Del.

Edwin M. Williams, Sc.

Printed by J. Basire



FRANKLIN INSTITUTE LIBRARY

A. Hancock, Del. Printed by J. Basire Edwin M. Williams, Sc.

Fig. 1.

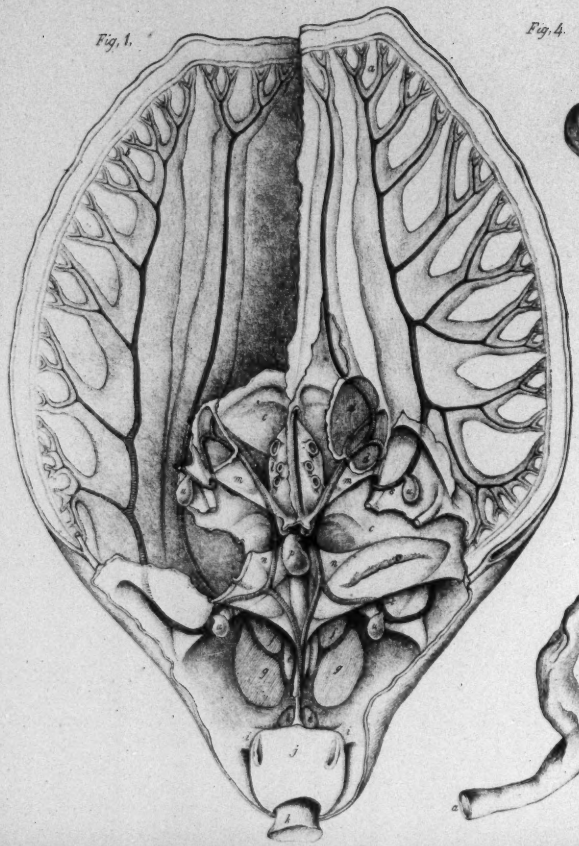


Fig. 4.

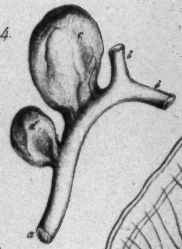


Fig. 2.

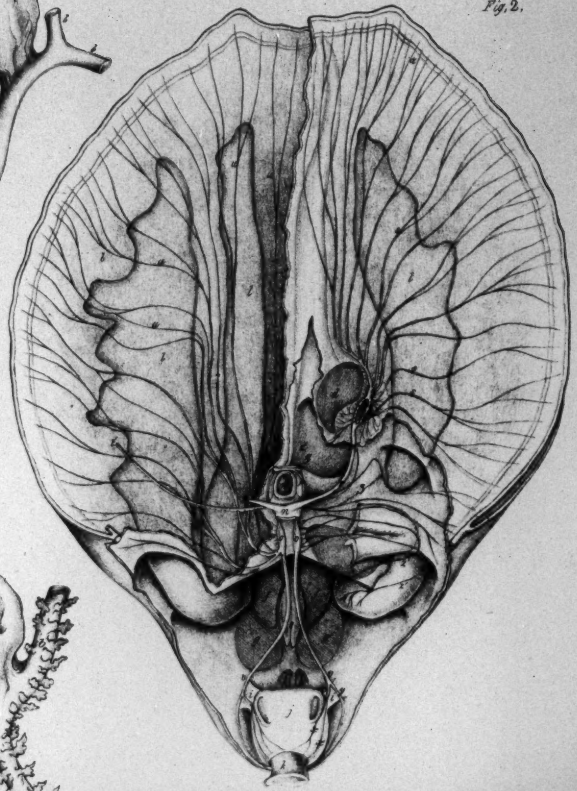


Fig. 3.

A. Hancock, Del.

Printed by J. Basire

Edwin M. Williams, Sc.

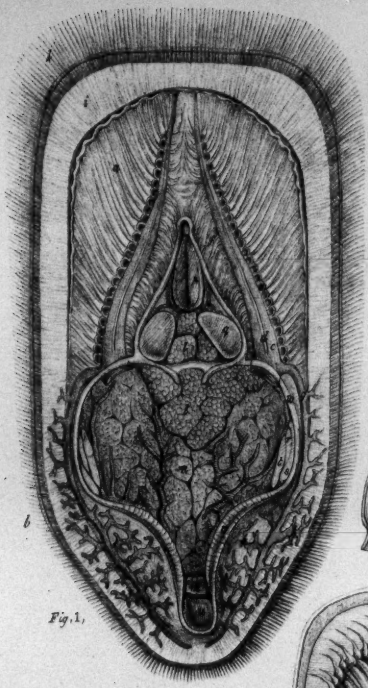


Fig. 1.

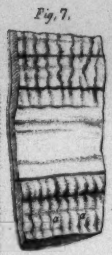


Fig. 7.

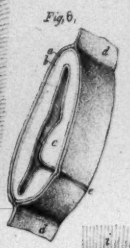


Fig. 6.

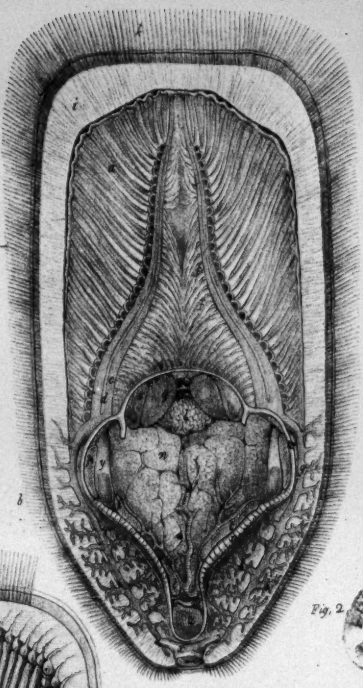


Fig. 2.

FRANKLIN INST. LIBRARY

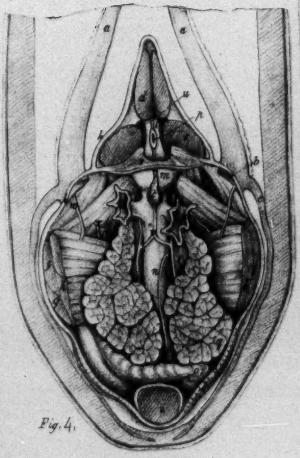


Fig. 4.

Fig. 3.

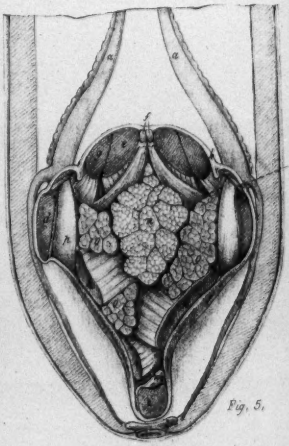
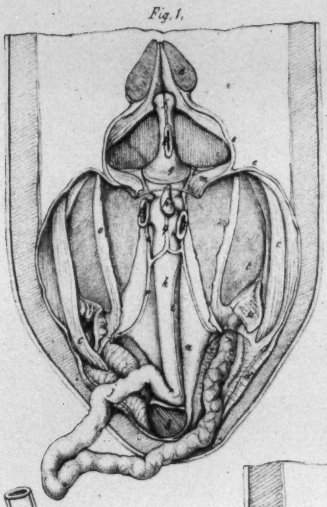


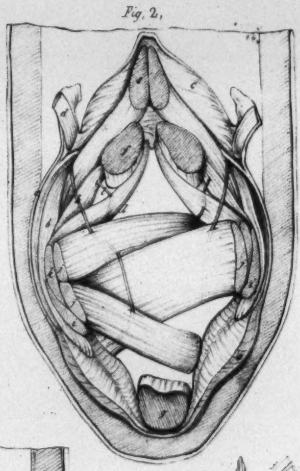
Fig. 5.

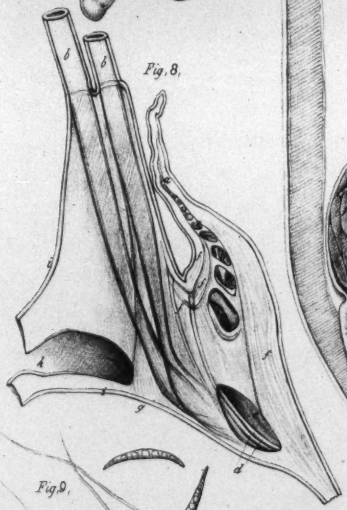
A. Hancock, Del.

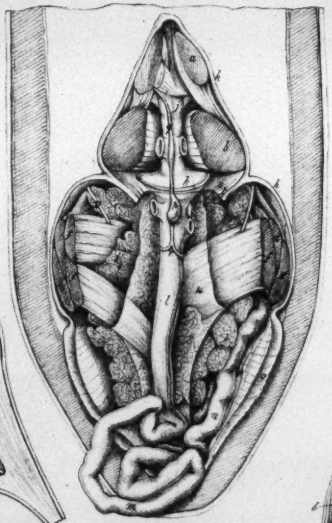
Edwin, M. Williams, Sc.

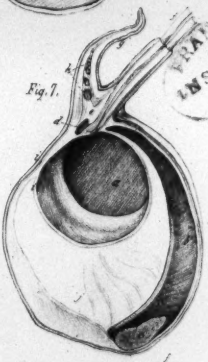
Printed by J. Basire.



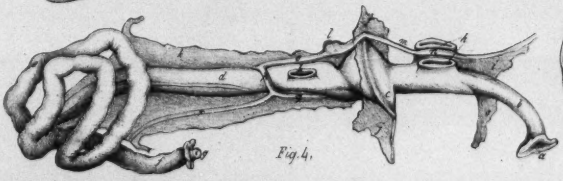


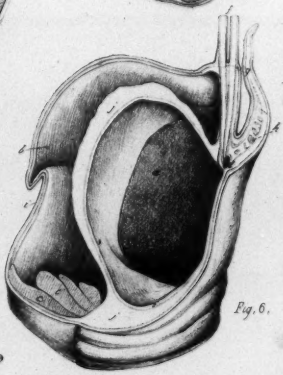






FRANKLIN INSTITUTE LIBRARY





A. Hancock, Del. Printed by J. Basire. Edwin M. Williams, Sc.

FRANKLIN INSTITUTE LIBRARY

A. Hancock, Del.

Edwin M. Williams, Sc.

Printed by J. Basire

J. Dinkel, del. & lith.

CHONDROSTEUS

FRANKLIN INST. LIBRARY

Reduced 1/12th

EUS ACIPENSEROIDES.

Printed by J. Basire.

Fig. 1.

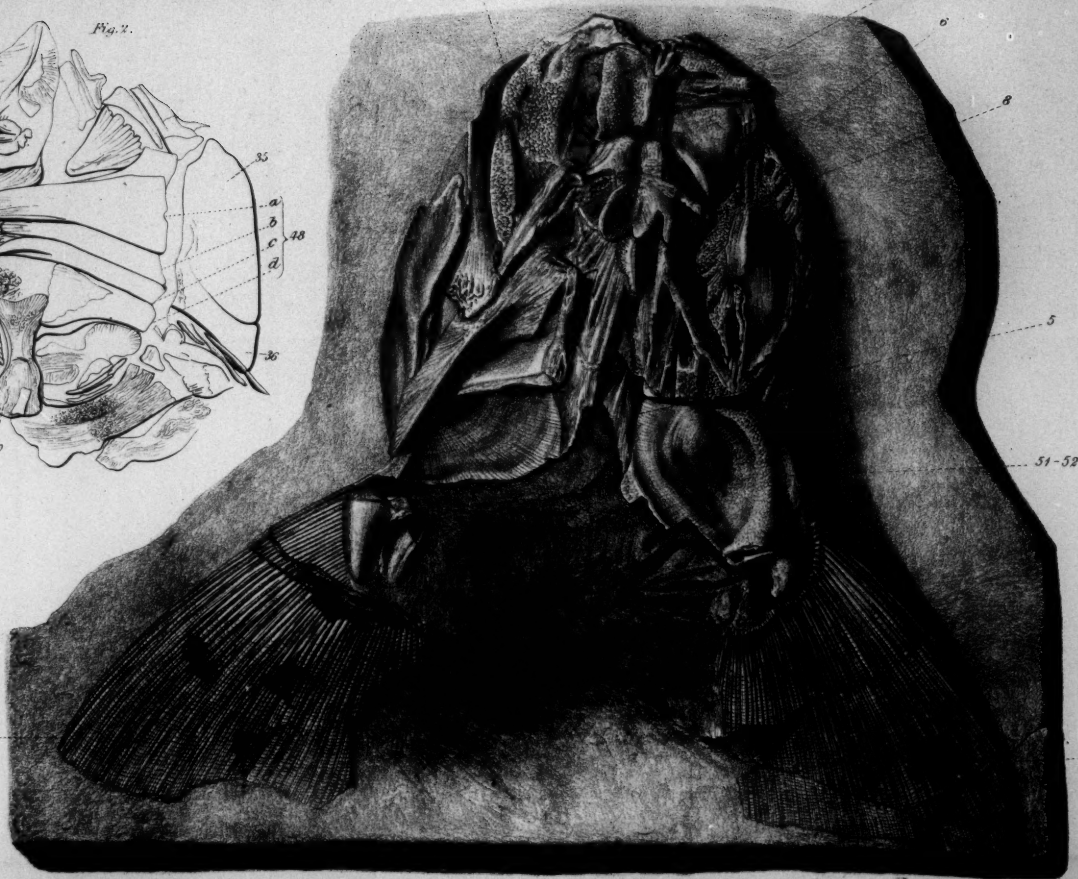
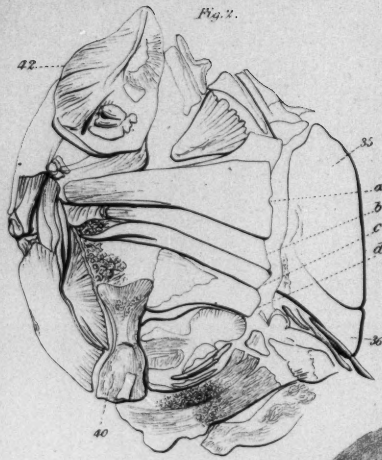


Fig. 2.

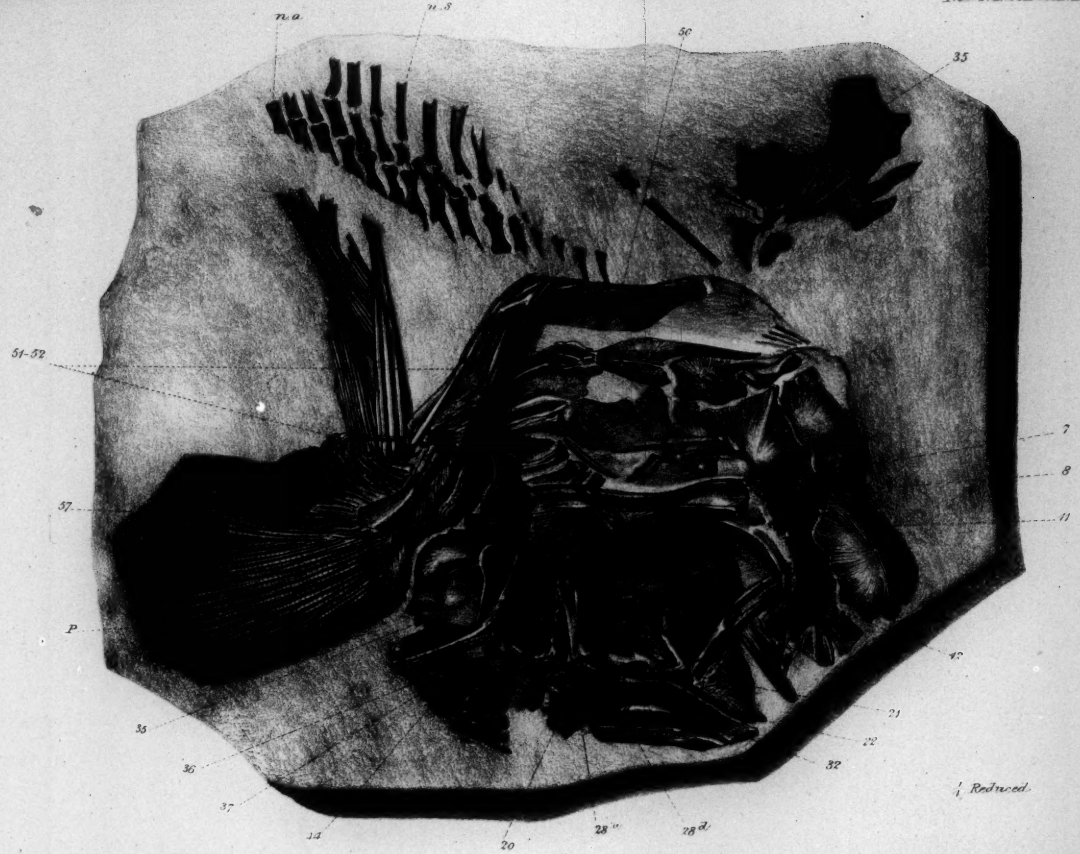


J. Dinkel. lith.

Reduced.

CHONDROSTEUS CRASSIOR. EGERTON.

Brooks by J. Basire



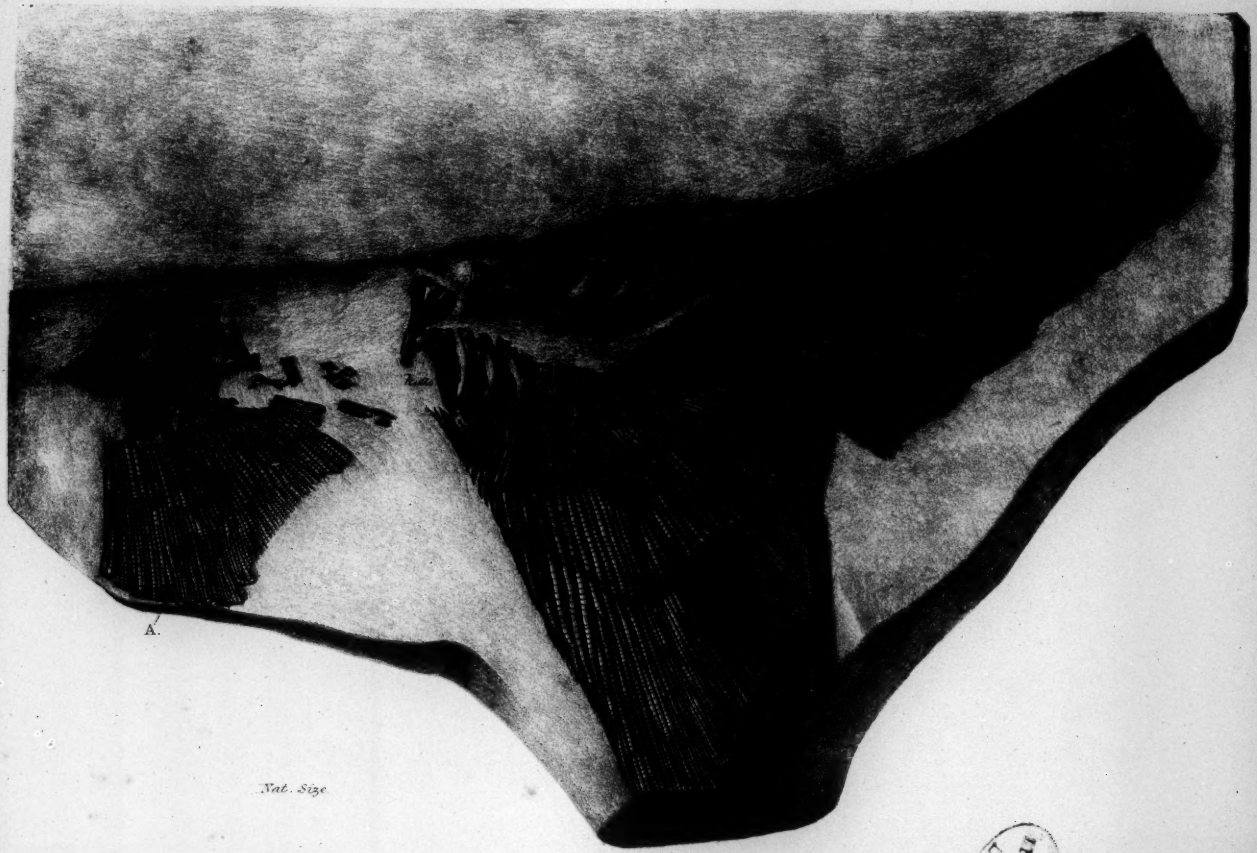
¼ Reduced.

CHONDROSTEUS ACIPENSEROIDES AGASS.

J. Dinkel. Lith.

Printed by J. Basire.

FRANK INSTIT LIBRA



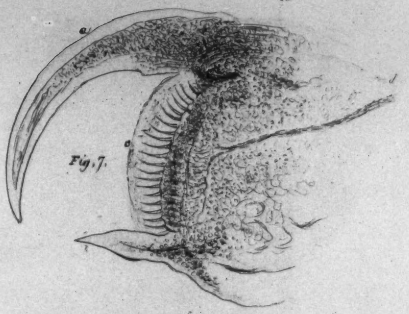
Nat. Size.

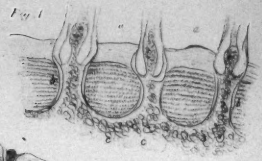
J. Dinkel. Lith.

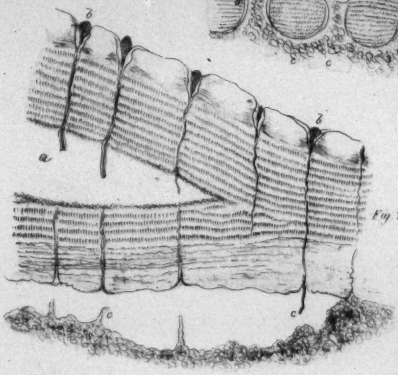
CHONDROSTEUS CRASSIOR EGERTON

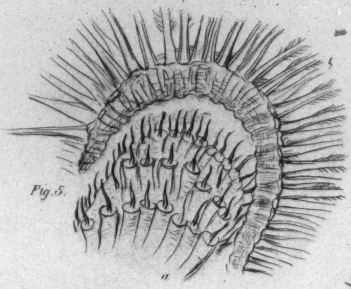
FRANKLIN INSTITUTE LIBRARY

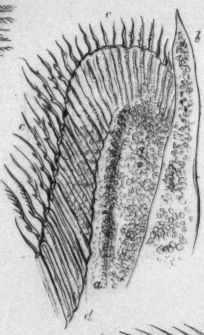
Printed by J. Basire.

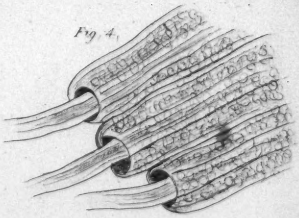


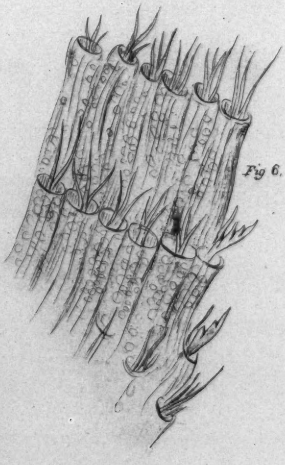


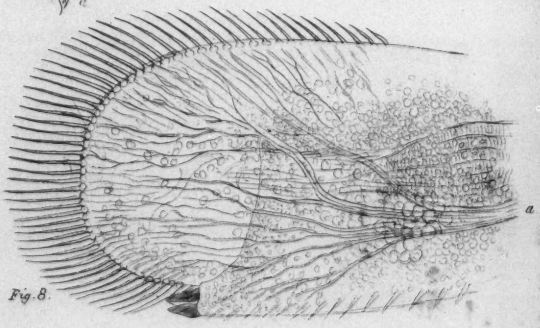












FRANKLIN INSTITUTE LIBRARY.

Edwin M. Williams Sc.

C. De M. del.